THE C. W. MANUAL

DESIGN AND CONSTRUCTION OF RADIO TELEGRAPH AND TELEPHONE TRANSMITTING EQUIPMENT

BY

JENNINGS B. DOW

PACIFIC RADIO PUBLISHING CO.
SAN FRANCISCO

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Ensign, U. S. N.

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PREFACE

Recently and rapidly the vacuum tube has risen from its place as a detector of the minutest signals to a generator of most powerful electric oscillations. The phenomenal rapidity of this change has filled even the most enthusiastic followers of the alluring art of radio with a spirit of awe, and there is every reason at hand to indicate that this development will continue until the most fantastic dream of radio science becomes an actuality.

This little volume has been written with the idea of placing before a world of experimenters who will carry forward the work of De Forest, White, Miller, and Hull, a brief, yet complete treatise on the design, construction and operation of continuous wave transmitters of the vacuum tube type.

The first chapter considers briefly the theory and operation of the triode as a generator of electric oscillations. The second chapter treats of tube transmitting circuits in general, while succeeding chapters deal specifically with the design and construction of continuous wave transmitters, from the smallest employing a single detector tube as an oscillator, to the largest employing one or more high power tubes of a quarter kilowatt output each—and these transmitters for operation with either alternating or direct current supply.

The author desires to express his indebtedness to the Bureau of Standards for a large portion of Chapter I, to the Acme Apparatus Co. for their co-operation in furnishing several pieces of apparatus which were used in developing the text, and to the Aluminum Company of America and the Belden Manufacturing Company for the tables used in the appendix.

J. B. D.

U. S. S. California, May, 1922.

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CHAPTER I

THE VACUUM TUBE TRANSMITTING CIRCUIT

THE reader is assumed to be familiar with the principles involved in the operation of the three-electrode valve, the triode, or to have access to the literature available on this subject. Consequently, to avoid duplication and to save space, we will begin by considering the vacuum tube circuit. With slight variation, but consistent with the words of Van Der Bijl,[1] the conditions that are necessary to make the tube act as an oscillation generator may be stated briefly as follows:

1. The tube must be capable of amplifying, that is, it must have an unilateral impedance which is occasioned by potential variations on the grid producing a greater effect on the current in the plate circuit (output circuit) than the effect produced on the current in the grid circuit by potential variations on the plate.

2. Part of the energy in the output circuit must be returned to the input circuit by suitable coupling of these circuits electro-statically or magnetically, and in order to insure a re-amplification of this energy, the output and input must be in phase.

3. An oscillating circuit must be attached to the tube, having inductance, capacity and resistance of such values as to make the tube oscillate at the desired frequency. These values should be such that a maximum efficiency is obtained with maximum output.

(1.) Thermionic Vacuum Tube, VAN DER BIJL (P267)

Fig. 1 shows a typical vacuum tube transmitting circuit—a Hartley circuit.

Fig. 2 shows this same circuit reduced to a simpler form for purposes of explanation. The antenna of Fig. 1 is represented by the dotted portion of Fig. 2.

The grid and filament of the tube in this circuit are connected to the branched circuit containing inductance and capacity, constituting the oscillatory circuit, in such a manner as to include a portion of the inductance of that circuit represented by the symbol L_g. In a similar way the inductance represented by L_p is included between the filament and plate.

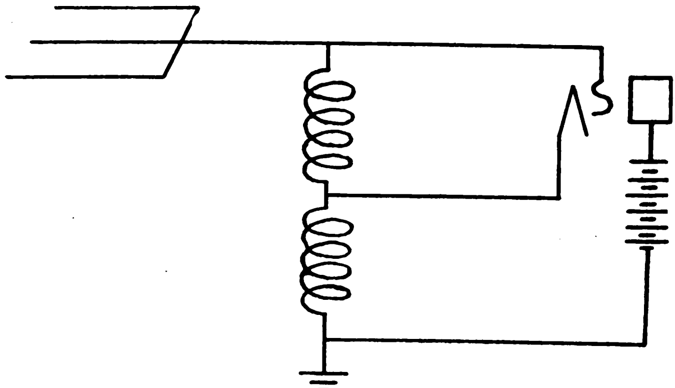


Fig. 1. The Hartley Circuit.

[2] Suppose first that the circuit is not oscillating. Because of the potential impressed upon the conducting path between filament and plate, a steady current will flow from plate to filament inside the tube and from filament through inductance L_p outside the tube. The magnitude of this current will vary with the voltage of the grid. It can become zero when the flow of electrons between filament and plate is made negligible by a highly negative potential on the grid, but it cannot reverse. A current can also flow from grid to filament inside the tube, the current returning from filament to grid through the inductance L_g in the external circuit. This latter current is appreciable only when the grid is positive with respect to the filament. Like the plate to filament current mentioned above, this current is also unidirectional

([2].) Bureau of Standards publication No. 355, L. M. Hull, Dec. 1, 1919.

and its magnitude is dependent upon the potential on the grid.

When the tube is oscillating, these currents will, of course, not be steady, but pulsating. The pulsating currents generated by the tube enter the circuit from the filament and leave it through the plate and grid connections. They are pulsating and not alternating on account of the unidirectional conductivity between filament and plate and filament and grid. The circuit CL_gL_p is resonant to these pulsating currents and an oscillatory current is generated and circulates

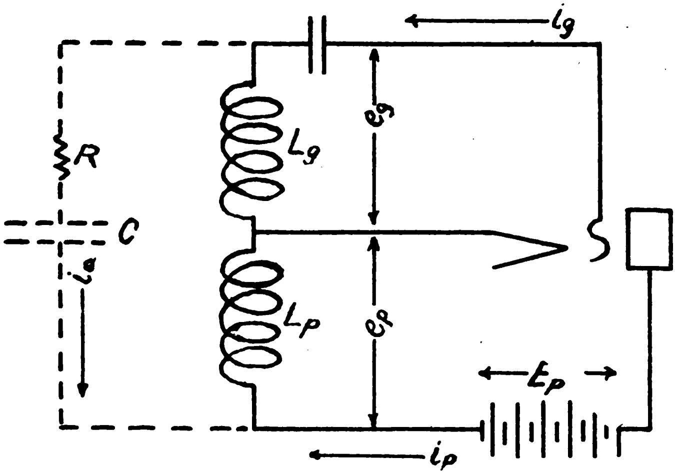


Fig. 2. Simplified Diagram of Hartley Circuit.

around this branched circuit, flowing through the capacity C and the inductances L_p and L_g. This current, which will be called the output current, can be many times greater in amplitude than either of the pulsating currents.

The pulsations in the steady current which flows during the stable condition from filament to plate are, as stated heretofore, caused by periodic variations in the potential of the grid with respect to the filament and these variations in grid potential are induced in the grid coil L_g by the output current. There is a similar potential induced by the output current across the plate coil L_p.

It is true of this circuit and typical of any circuit for generating oscillations, that during the portion of the cycle of

the output current when the grid is positive with respect to the filament as a result of the potential difference across the coil L_g, the voltage drop between the plate and filament connections (across the inductance L_p) is such as to oppose the potential of the plate battery and hence to reduce the potential between filament and plate inside the tube. During the other part of the cycle when the grid is negative with respect to the filament the potential acting between plate and filament is increased above that of the stable potential of the plate battery. During the portion of the cycle when the grid is positive with respect to the filament, current flows within the tube between the grid and filament and this current increases as the grid becomes more positive. The direction of the current flow is in the direction of the potential, that is, from grid to filament inside the tube and from filament to grid outside. Further, as the grid becomes positive with respect to the filament, there is a resultant increase in the current flow between the plate and filament of the tube, even though the plate potential on the tube is being reduced. This increase is limited, when the stable oscillating condition has been reached, by the saturation effect, which may occur at lower values of plate current than that corresponding to the total filament emission owing to the loss of electrons to the grid.

As has been stated, the plate current wave is distorted at the other extreme of the cycle—that is, when the grid is negative—by rectification effects; moreover, the grid current is always pulsating, and is zero for a considerable part of a cycle, while the grid is negative. Consequently, the waves of current supplied to the circuit between filament and plate, and filament and grid (Fig. 3) are each composed of a direct or average constituent, a fundamental constituent corresponding in frequency to that of the output current, and a number of higher frequency or harmonic constituents.

The useful oscillating output current depends neither upon the direct or average values of the plate and grid currents nor upon the multiple frequency constituents; it is determined solely by the fundamental constituents of these currents, to which the same consideration as regards direction and phase relations apply as have been roughly stated with regard to the distorted current waves.

Thus, speaking only in terms of useful current constituents, a sinusoidal alternating current flows in the grid circuit in phase with the alternating e. m. f. across the inductance L_g, and therefore represents a withdrawal of power from the output circuit, which power is expended within the tube. On the other hand, a sinusoidal, alternating constituent of plate current flows in opposition to the e. m. f. across the

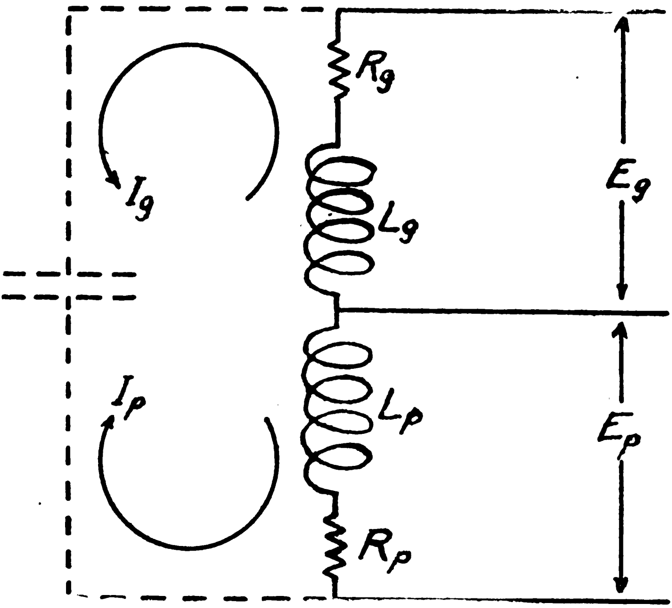


Fig. 3. Showing Direction of Grid Current and Plate Current.

inductance L_p; this means that power is being supplied to the output circuit from the plate circuit of the tube. As will appear later, the impedance of the output circuit to all frequencies that are harmonic multiples of the fundamental is very great. Hence there are no appreciable multiple frequency constituents of the current circulating in the output circuit and the alternating e. m. f.'s across the inductances L_p and L_g are in all cases practically sinusoidal. Consequently the useful power supplied by the tube can be determined in terms of the alternating e. m. f. across L_p and the fundamental constituent of the plate current. If we would

neglect the grid current, this would be the power available for dissipation in the resistances. As the output current increases, the amplitudes of the alternating e. m. f.'s across the plate and grid inductances increase proportionately. The alternating grid current increases more and more rapidly as the amplitude of the plate e. m. f. becomes larger. On this account, the power loss to the grid increases. The power supplied by the plate increases with increasing plate potential, but as the grid potential increases the effective saturation current is reached when the grid is positive and the plate current becomes zero for an appreciable part of the cycle when the grid is negative. Consequently, a continued increase in the amplitude of the output current results chiefly in an increase in the harmonic constituents of plate current without greatly increasing the fundamental. Obviously, then, a condition of stability ensues when the power supplied by the fundamental of plate current minus the power dissipated by the fundamental of grid current is just equal to the power dissipated by the output current in R_g, R_p and R_c.

CHAPTER II

C. W. CIRCUITS TO DATE

There are as many as five vacuum tube circuits that may be considered of primary importance. Only two of these, however, are found in common use in modern transmitting circuits, namely, the Hartley circuit and Heising's modified Colpitts circuit. Meissner's circuit, while used to some extent in its basic form, resolves itself into a modified Hartley or Colpitts circuit in practice. Its approach to either of these depends upon the constants of the circuit.

Both the Hartley circuit and Heising's modified Colpitts circuit possess certain advantages and disadvantages, all of which are not common, and the experimenter, in selecting one will do well to consider each. For example, the Colpitts circuit, while highly efficient, does not well adapt itself to flexibility insofar as rapid change of wavelength is concerned. This disadvantage was largely overcome by Heising's alteration. The Hartley circuit, probably the most efficient, retains its efficiency only through the narrow band of wave lengths for which a given installation is designed; this, because the variable feature is vested in inductance rather than in capacity. Large amounts of inductance are obviously necessary for operation at the longer wave lengths, and when using only a small portion of this inductance for the shorter wave lengths, there is added resistance in the circuit resulting from the so-called "dead end effect" and from corona losses which are very apparent in any open end inductance adjacent to circuits where high frequency currents of any magnitude are flowing.

Fig. 4 shows the common Hartley laboratory circuit as used to generate sustained oscillations for calibration work, heterodyning incoming signals, producing high potentials for testing insulation, etc. If the resistance of the circuit CL_gL_p is sufficiently low, a simple circuit of this kind may be made to generate oscillations from a few per second to upwards of

3,000,000 per second. If. in place of the concentrated capacity C, an antenna having distributed capacity and appreciable resistance is substituted, the band of frequencies at which the circuit will oscillate will be restricted to a comparatively narrow range. In this circuit, both inductances L_p and L_g necessarily coupled to obtain the required grid input, are a part of the oscillatory circuit and must be wound with low resistance wire, tubing, or tape in order to keep the resistance of the circuit as low as possible. In practice, in transmitting circuits, L_g is exterior to the oscillating circuit

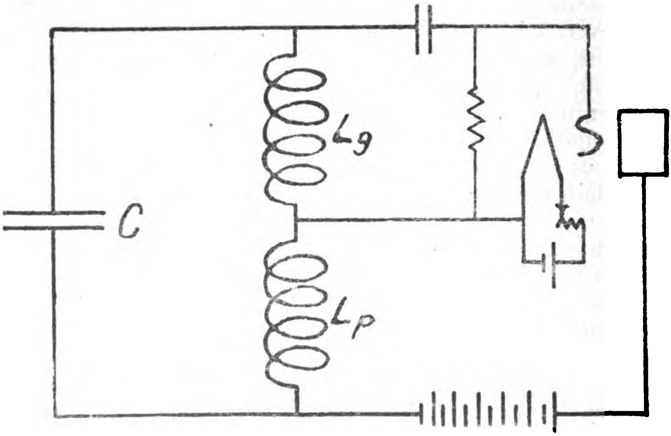


Fig. 4. Hartley Circuit as Used in the Laboratory.

and may be wound with almost any kind of conductor. In so far as the supply of power to this circuit is concerned, it is of the series power circuit type—the plate battery or generator is in series with the plate and is unshunted by capacity. Here the plate circuit is not a part of the oscillatory circuit and the current which flows in this circuit is pulsating rather than oscillating as previously explained.

In Fig. 4, a small capacity and large resistance are used to obtain the required negative potential on the grid. With this arrangement the grid obtains a positive potential only during the small fraction of the cycle when the grid leak current is building up to rob the grid of its positive charge. Notwithstanding the fact that the grid attains a positive charge during

a small fraction of each cycle, which results in a grid to filament current inside the tube, the capacity-grid-leak resistance method of obtaining the required negative potential is more efficient than the method of inserting a grid battery in the circuit. In using the latter method the plate potential must be increased to a much greater value before oscillations will start, than when the former method is used. The value of the current in the oscillating circuit is greatly dependent upon the value of the grid leak resistance, which will vary with the type of the tube used, but will usually lie within the limits of 5,000 to 12,000 ohms.

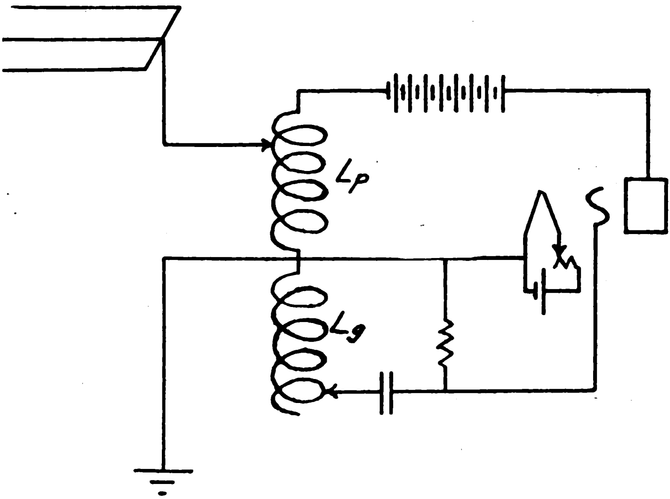


Fig. 5. Hartley Circuit as Used in Practice.

Fig. 5 shows the Hartley circuit as used in practice. Here the inductance, L_g, is not a part of the oscillating circuit, but is merely coupled to the oscillating circuit to obtain the required input for the regeneration of oscillations. The variable feature of the inductance L_g may be obtained either by a fixed coil inductively related to L_p, with a variable contact, or by a coil having a fixed amount of wire in circuit at all times, but so mounted as to provide a means of changing the degree of coupling with L_p, or by a combination of both of these methods as found in some of the more refined sets. In this circuit, the filament and grid are more or less

strongly tied to earth which results in the plate only being "hot." This is a feature which is very desirable in a power circuit where high voltages are used. The period of oscillation of this circuit is dependent upon the value of antenna capacity and inductance, and the inductance L_P. At very high frequencies, however, intra-electrode capacities and other capacities and inductances in the circuit may influence the period of oscillation, and in all circuits these values, together with the resistances, determine the upper limit of oscillation. In the design of the transmitters to operate at short wave lengths (wave lengths under 250 meters) the Hartley circuit is recommended. As a matter of information the General Electric Company has been able to obtain waves six meters long with such a circuit. At this wave length, which corresponds to a frequency of 50,000,000 cycles per second, the inductances resolve themselves into nothing more than the straight connecting wires.

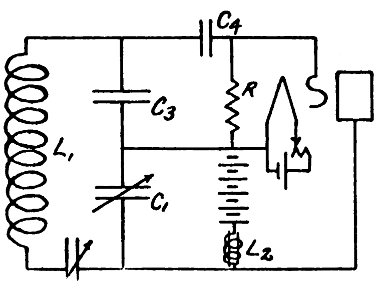


Fig. 6. Colpitts Laboratory Circuit.

Fig. 6 shows a Colpitts laboratory circuit. In the case of the Hartley circuit, the coupling between input (grid) circuit and output (radio frequency) circuit was obtained inductively. In the Colpitts circuit, the coupling between input and output is capacitive and is varied by changing the value of the capacity C_1. In changing this capacity as required in adjusting the circuit for most efficient operation, the period of oscillation of the circuit $L_1C_1C_2C_3$ is changed and it is necessary to change the capacity C_2 an amount necessary to obtain the desired period of oscillation. This double adjustment is somewhat of a disadvantage in practice. In this circuit, the plate potential is applied across the capac-

ity C_1, and in order not to affect the oscillating circuit $L_1C_1C_2C_3$ a radio frequency choke L_2 must be inserted in the plate supply lead as shown. The matter of obtaining the proper value of this choke inductance will be considered in detail later. The capacity grid-leak resistance method of obtaining the required negative potential on the grid is used here, also.

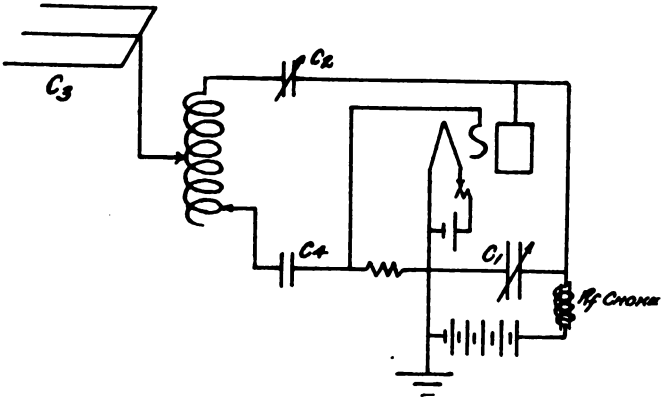


Fig. 7. Colpitts Circuit as Used for Transmission.

Fig. 7 shows the Colpitts circuit as applied to a power transmitting circuit possessed of an antenna which is represented by the capacity C_3.

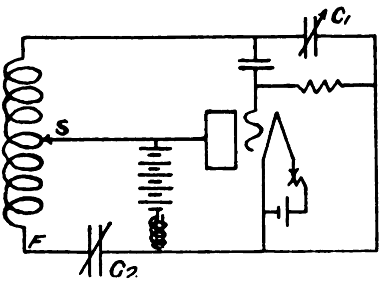


Fig. 8. Heising Circuit in Theory.

Credit is due Heising for the circuit represented in Fig. 8. This is one having a number of very desirable features. The coupling between input and output is varied by changing the

position of the contact S. If contact S is moved along the inductance to the point F and a variable capacity is inserted in the circuit between the plate and F, the circuit shown in Fig. 6 will result. By means of Heising's variable contact S, then, it has been possible to eliminate the variable capacity C_2 of Fig. 6 and at the same time provide a method of changing the coupling between input and output without materially changing the period of oscillation of the circuit.

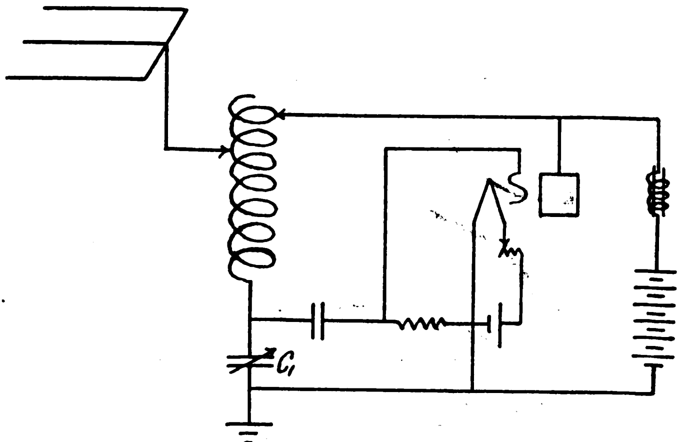


Fig. 9. Heising Circuit in Practice.

The standard Heising circuit found in practice is shown diagrammatically in Fig. 9. It will be observed in this figure that only two movable contacts on the inductance are necessary as compared to three in the case of Hartley's circuit. This simplifies the design to a certain extent. It may be well to state in passing, that admirable as this circuit is for low powered installations, it is not so well adapted to installations requiring great flexibility at high powers—this by virtue of the facts, that the inductance is all "hot," and that it is difficult to design a continuously variable capacity such as the one required at C_1 without resorting to oil for the dielectric.

The Heising circuit employed by the Western Electric Company in the much used CW 938 sets is shown in Fig. 10.

Here one finds that instead of connecting the negative side of the plate supply circuit to earth as in Fig. 9, it is connected to earth thru the capacity C_2. This is a protective measure since in Fig. 10, if either the antenna becomes grounded or the capacity C_2 breaks down under an electro-

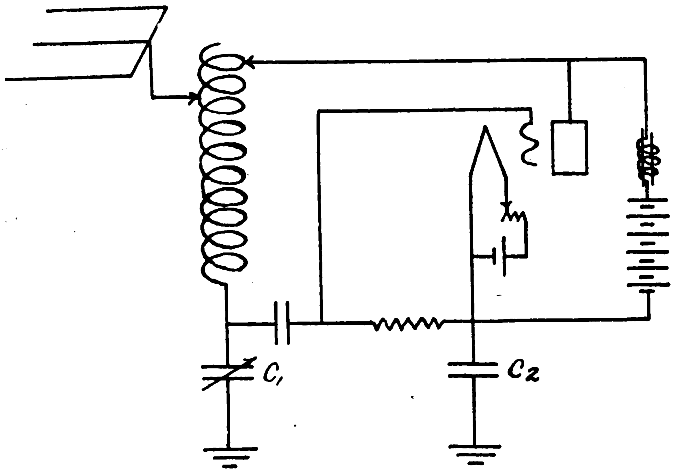


Fig. 10. Heising Circuit as Applied to the 938 set.

static or mechanical strain, the generator supplying the plate potential will not become short circuited. The condenser, C_2, should have a capacity in excess of 0.2 micro-farad.

Modulating Systems

Fig. 11 illustrates the power modulator method of controlling an oscillating vacuum tube at voice frequencies and represents one of the most successful though not the most efficient method of accomplishing this. For a single tube oscillating circuit employing a tube rated under 100 watts and for multiple tube circuits employing two or three smaller tubes, this method of obtaining modulation at voice frequencies is recommended. With larger single tube circuits and circuits in which more than three small oscillator tubes are used, one of the various other methods of modulation should be used to promote overall efficiency.

The power modulator circuit of Fig. 11 is due to Heising and it is here used to control a Hartley oscillating circuit. In a similar manner control of a Heising oscillating circuit may be had, as in Fig. 12. In the above mentioned circuits L_1 is

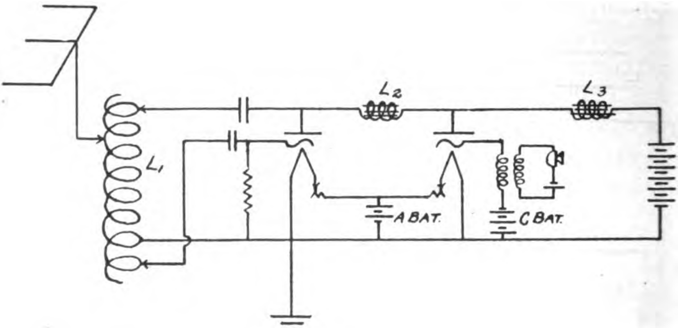


Fig. 11. Power Modulator Method of Control for Hartley Circuit.

the low resistance inductance in the oscillating circuit, L_2 is a radio frequency choke so constructed as regards distributed capacity between turns as to prevent radio frequency currents from entering the modulator tube circuit. At the same time,

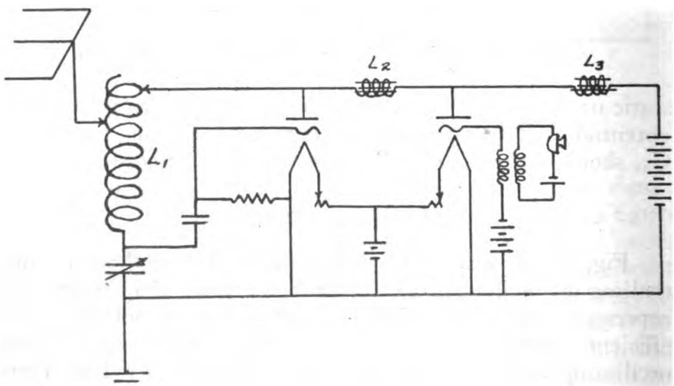


Fig. 12. Power Modulator Method of Control for Heising Circuit.

this choke must offer little impedance to currents at voice frequencies. These latter currents, though pulsating in nature, behave much the same as alternating currents, in large inductances. L_3 is an audio frequency choke which is placed

in series with the generator supplying the required power to the plates of the oscillator and modulator tubes to insure that the current supplied by the generator will be as steady as possible. Theoretically, with a choke of the correct value for this purpose, and with other circuit constants of good proportions, the supply of current by the generator will be constant and the currents in the plate branches of the network will merely shift between the tubes. This condition is rarely found in practice, however. This may appear somewhat misleading to the layman who inserts an indicating device such a milliammeter in the generator circuit and notices fluctua-

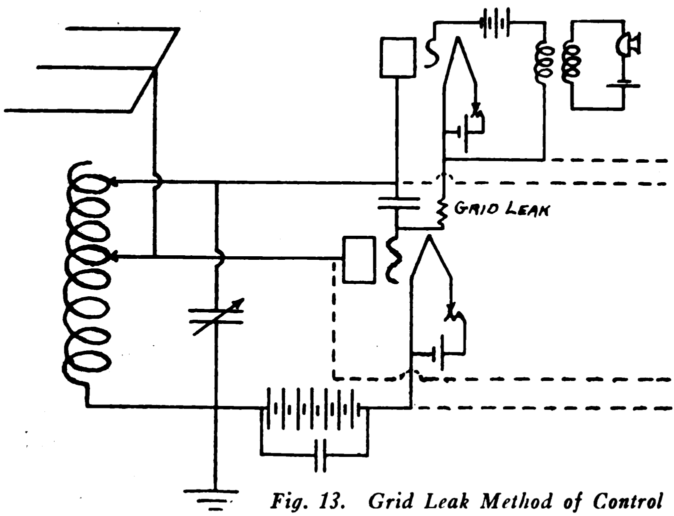


Fig. 13. Grid Leak Method of Control

tions in the current evidenced by a swaying needle. The frequencies which cause this swaying are harmonics of audio frequencies or other disturbances below the lower limit of true audio frequencies. Such an indication is however a reasonable test of modulation, though not a true indication of voice modulation.

It will be observed in Figs. 11 and 12 that a battery is placed in the circuit at C to obtain the necessary negative grid potential. The capacity grid leak resistance method of bringing about a negative potential cannot be used here as in the case of the oscillating tube.

In the circuits explained above the secondary of the modulation transformer is directly in series with the grid. The grid potential then is dependent upon the ratio of turns in primary and secondary, and the rate of change of current in the primary. If the potential variations thus produced on the grid are excessive or insufficient, poor modulation will result.

Fig. 13 shows another method of controlling an oscillating tube circuit at audio frequencies. This is known as the grid-leak resistance method of control and consists in controlling the grid-leak resistances of the oscillator tubes with

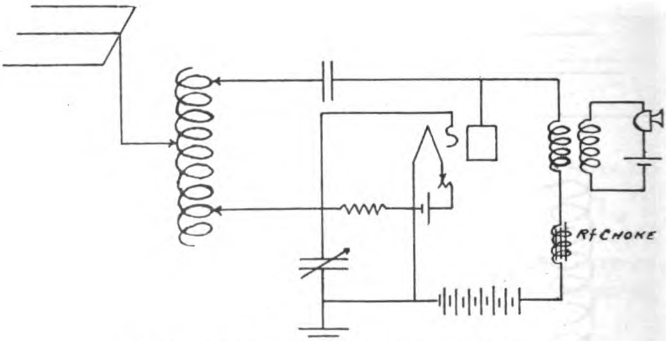


Fig. 14. Control by Modulation Transformer Secondary in Power Circuit.

the variable resistance path between plate and filament of a separate three electrode valve. The manner of controlling this latter valve is the same as that previously explained. This is a very simple method, but care must be taken in selecting the grid leak resistance values for the oscillators. By connecting several oscillators in parrallel and using grid condensers and grid-leaks, one small tube may be made to control the combined output of several power oscillators. The dotted lines in Fig. 13 illustrate the method of connecting the several oscillator tubes.

In Fig. 14, control is accomplished by inserting the secondary of the modulation transformer directly in the power supply circuit. Using a simple receiving tube as an oscillator the author has obtained remarkable results with this system. It is not well adapted to the control of large power tubes, however.

Alternating Current C-W Circuits

Of late, vacuum tube transmitters designed primarily for telegraphic purposes have been utilizing the easily obtained high potential alternating currents for the necessary power supply. This is because high voltage direct current generators require considerable care and attention and are expensive.

One of a number of circuits employing alternating current for both plate and filament supply is shown in Fig. 15. Here a single transfomer having two secondaries is used.

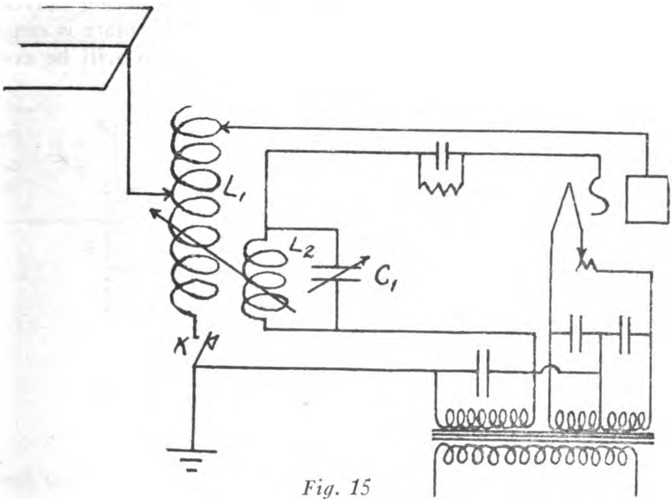


Fig. 15

The mid-point of the filament winding is tapped to eliminate the "hum" which would be caused by connecting the grid to one end of the winding. The transformer secondaries are bridged as illustrated in the diagram by small condensers designed to withstand the impressed electromotive forces. The correct values of these capacities will be found to be approximately .002 micro-farad in the case of the one bridging the plate supply secondary and almost any value greater than 0.2 in the case of the others. Care must be exercised in using capacities across a supply of high potential alternating current, as a power circuit involving high currents is liable to result. These currents while termed "wattless," result in large copper losses in the windings. The circuit of

Fig. 15 illustrates the method referred to earlier in this chapter, of obtaining the required grid input by a variable coupling device having a fixed amount of wire in the circuit at all times. L_2 is the input inductance and is coupled to L_1 by either the sliding tube or variometer method. It is bridged with a capacity C_1 to facilitate adjustment. The conventional capacity grid leak resistance method of maintaining a negative grid potential is used. This circuit may be termed an ideal one in so far as simplicity is concerned. It oscillates easily, and is very efficient, but it possesses the disadvantage of utilizing only one-half of the alternating current cycle. During the part of the cycle when the plate is negative no oscillations are produced. This circuit will be considered in detail later.

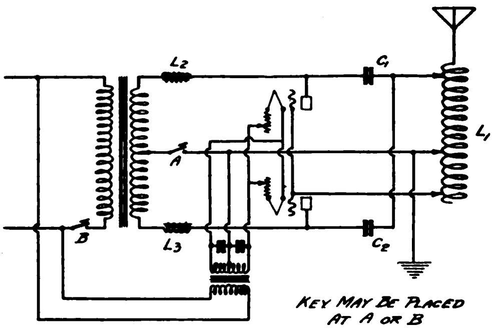


Fig. 16

A circuit utilizing both sides of the cycle is illustrated in Fig. 16. This is a simple Hartley circuit using two tubes. The inductances L_2 and L_3 are radio frequency chokes placed in the circuit to prevent absorption of the high frequency oscillations in the distributed capacity and resistance of the transformer T. Their use is imperative in this circuit. The capacities C_1 and C_2 should be quite large, preferably in excess of .005 micro-farad each. Without these, the transformer secondaries supplying the high voltage to the plates would be short circuited by the inductance L_1. The use of these is also imperative in this circuit. With a transmitting circuit of this kind using two 50 watt tubes, the author has obtained an overall efficiency of 45 per cent.

If the key is placed in the circuit at B, the life of the filaments is impaired considerably by the continuous shock to which they are subjected in transmitting. See Fig. 17 for method of lessening this shock, where it is proposed to have the filaments heated at all times, but only at their operating temperature when the key is pressed. This should meet with great favor among experimenters whose supply of tubes is limited. Since the core of the filament transformer is active at all times, the high voltage transformer must be a separate one. The filament transformer has two primary coils, one of which is connected across the alternating current supply

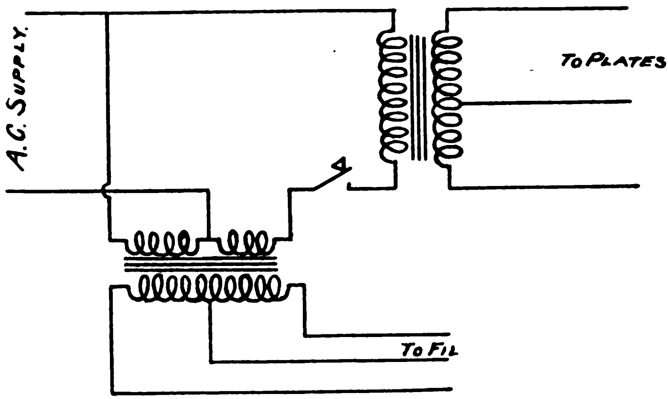


Fig. 17

and provides a sufficient potential difference in the secondary to heat the filaments of the tubes, the other being paralleled with the former through the primary of the high voltage transformer when the key is held down. The currents in the two filament transformer primaries are not exactly in phase owing to the difference in impedances of the two windings, but this should cause no trouble, since the capacity of this transformer is quite low and magnitude of these currents is small.

Polyphase C-W circuits have made their *debut* into the curriculum of the experimenter of late and up to the present time, have given every indication of remaining. By the use of multiphase currents many things are gained—the low frequency note is eliminated and greater output may be obtained with less straining of the tubes. See Fig. 18 for a circuit

employing three phase alternating current. In this circuit only one side of each cycle of each phase is used and instead of a disadvantage as in the case of single phase supply, this feature presents a decided advantage as the tubes are idle during a portion of the time and consequently have an opportunity to dissipate the heat generated. In the single phase circuit this idleness resulted in a low frequency hum which was objectionable, particularly when attempting to control the output telephonically. In Fig. 18, the so-called series

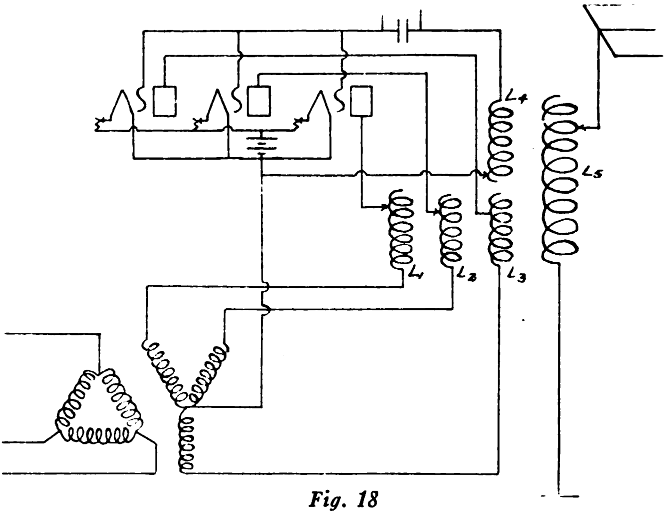


Fig. 18

power feed circuit is employed, which eliminates the use of radio frequency choke coils. The three inductances L_1, L_2 and L_3 are in the plate circuits of their respective tubes only and as a result only a unindirectionally pulsating current flows. This rising and falling unindirectional current induces in the inductance L_5 the radio frequency current used as the carrier wave. L_4 is coupled inductively to L_5 to obtain the necessary grid input. Separate grid condensers and grid leaks should be used for best results, although one grid leak and grid condenser will be found quite satisfactory. Overall efficiencies of 50 per cent may be obtained with such a circuit as the one outlined above, and, as will be found below, a three phase alternating current may be employed to supply the necessary plate potential for tubes controlled telephonically.

Fig. 19 represents such a phone set and one which has actually demonstrated the utmost practicability. Three tubes connected as shown are used as oscillators, and Heising's system of modulation is employed to control these tubes. The inductances L_1, L_2, L_3, L_4 and L_5 are coupled together. No particular difficulty presents itself in accomplishing this, for five pancake ribbon inductances of the type used in the Navy standard field equipment were used without alteration in the

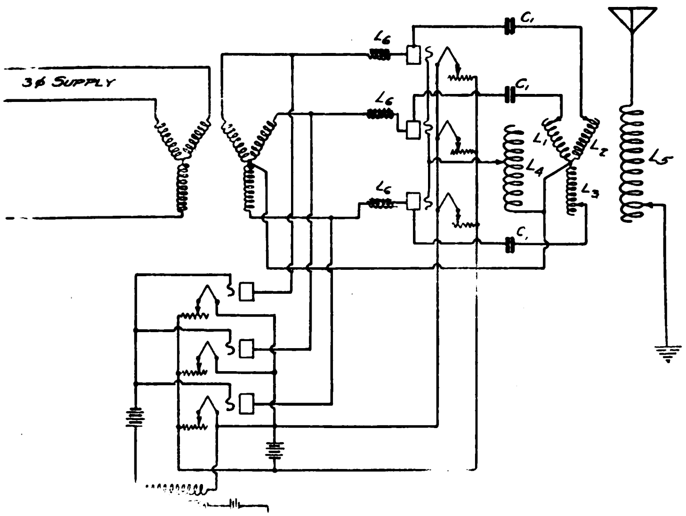


Fig. 19

original experimental set used by the author and excellent results were obtained. The capacities C_1 are all in excess of .01 micro-farad and are used to prevent the transformer secondaries from becoming short-circuited through the inductances L_1, L_2 and L_3. A radio frequency choke coil L_6 is placed in each transformer secondary lead for reasons previously explained. It will be observed that the series power feed circuit is not employed here as in Fig. 18. The overall efficiency of a circuit of this kind will compare favorably with one of equivalent output employing direct current, and in using the ordinary 3 phase 60 cycle supply, the audible ripple in the carrier wave is hardly appreciable during conversation.

The circuits that have just been considered, use unrectified alternating current on the plates of the tubes and if anything less than three phase supply is used for this purpose, difficulty will be experienced in adapting the circuit to voice modulation since a low frequency ripple will be present in the re-

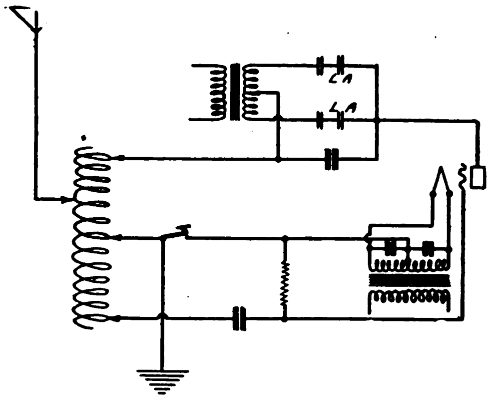


Fig. 20

ceived signal. If it is desired to utilize the easily obtained high voltage single phase alternating currents for the plate supply of phone equipment, the experimenter will do well in rectifying the same in a manner suggested in Fig. 20, or by one of the various other means outlined in detail in a latter chapter. In Fig. 20 an electrolytic rectifier is used. This method, while simple, and probably the most inexpensive from the experimenter's point of view, requires more or less constant attention and is objectionable for that reason.

The Power Amplifier

Probably the most interesting improvement in vacuum tube circuits that has come out in recent years is the use of the power amplifier in radio phone circuits. Little use, however, has been made of this adjunct by the average experimenter. By way of definition to the uninitiated, the power amplifier is a device used to reproduce in greater magnitude currents having a pulsating or alternating nature. The ordinary power modulator scheme of controlling an oscillating vacuum tube circuit, (Fig. 19) is limited by the ability of the microphone through the medium of the modulation transformer to control the modulator tubes, which must, for

the best results, be equal in number and power to the oscillators. This limitation results from the fact that it is very difficult to design a voice amplifier of high power that will operate without distortion.

Fig. 21 illustrates the use of the power amplifier in connection with a radio-phone set of low power represented by T. A_1 and G are respectively the antenna and earth connections of such a set. The capacity C_1 which should be variable and the inductance L_1 represent a dummy antenna circuit for the radio-phone T. C_2 is a capacity sufficiently large as not to affect the period of oscillation of the circuit $C_1L_1C_2$

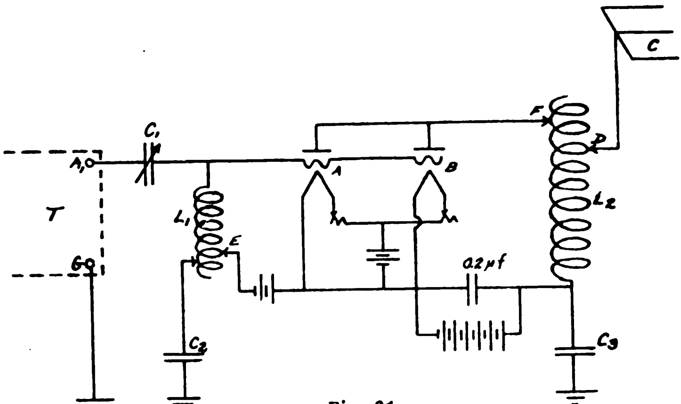


Fig. 21

plus the internal circuit of T. This capacity together with that of C_3 are placed in the circuit to prevent a shortcircuiting of the source of high potential to the power amplifier and T. The potential variations across the inductance L_1 are impressed upon the grids of the amplifier tubes, which, with proper circuit adjustments, reproduce the output of T in greater magnitude depending upon the size of the tubes A and B. The adjustment of L_1, while quite critical, is not difficult to make.

The proper procedure for adjusting such a circuit as shown in Fig. 21 is as follows: Adjust the circuit C L_2 C_3 to the wavelength desired by moving the variable contact D along the inductance. Then adjust the capacity C_1 until the antenna current is a maximum and at the same time alter the position of the tap E to obtain the best value of grid poten-

tial. Last, shift the plate tap, F, until a second maximum antenna current is obtained. Using a simple arrangement of this kind employing a Western Electric Company 5 watt phone set at T and two 5 watt tubes in the power amplifier, a laboratorian at Mare Island, California, succeeded in communicating by voice with an amateur in Portland, Oregon, a distance of approximately six hundred miles. In a similar manner much larger tubes at A and B could be controlled

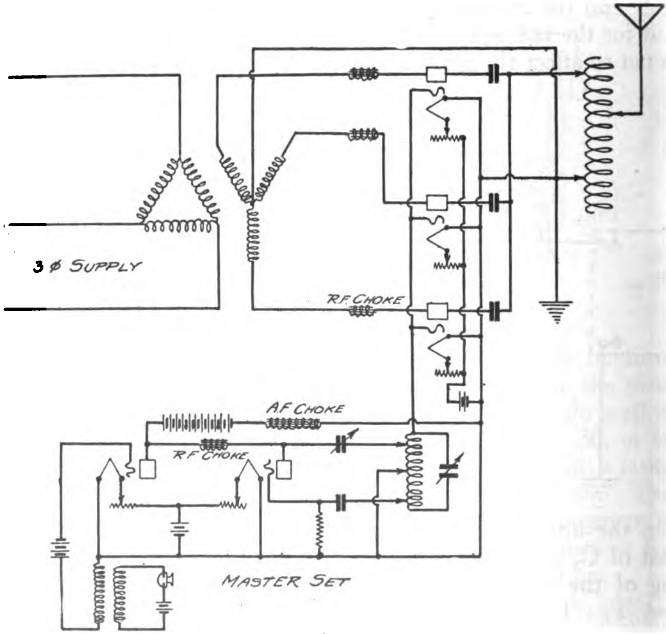


Fig. 22

by T, giving a greater range of communication. The details of a 10 watt power amplifier such as the one described above will be forthcoming in a later chapter.

Fig. 22 shows a 5 watt voice amplifier controlling a 5 watt oscillator which in turn controls the entire output of a 750 watt power amplifier supplied by three phase alternating current at 4,400 volts. The efficiency of such an arrangement is very great when compared to that of the power modulator system of control and very little voice distortion is obtained.

CHAPTER III

EXPERIMENTAL PHONE CIRCUITS

The scope of the present chapter will be limited to the development of two simple radio-phone circuits with which the experimenter may study the principles of operation involved and, in general, the factors which govern the operation of oscillating vacuum tube circuits for transmitting purposes.

The Design and Construction of an Inexpensive One-eighth Watt Experimental Phone Set

In the development of the subject matter above, certain factors which are to govern the design, will be stated briefly as follows:

1. The apparatus must operate from a source of direct current having an e.m.f. not exceeding 110 volts.
2. In order that the apparatus may be constructed at a minimum of expense, one tube only will be used, and by virtue of the limiting e.m.f. for plate supply, the circuit must be designed to use the ordinary receiving tube as an oscillation generator.
3. The band of frequencies at which the circuit must operate will be restricted to those corresponding to wavelengths between 200 and 350 meters.
4. In order that flexibility, so necessary for experimental work, may be had, the design will be further limited to that of a laboratory *lash-up*. This will enable the author as well as the experimenter to confine his efforts to the circuit itself, and to the construction of the component parts, rather than to an array of mechanical details.
5. It is assumed that the apparatus herein considered will be used with an antenna having a capacity of 0.0004 to 0.0008 micro-farad.

Two circuits are available for this purpose. See Fig. 14 and Fig. 23. The difference lies in the location of the modulation transformer in the circuit.

Let us consider first, the matter of high voltage supply to the plate. A voltage of 110 has been selected because it is a commercial value and in case it is not obtainable as such, it may be quite easily obtained from an arrangement of batteries. If its source is a generator, it may be necessary to

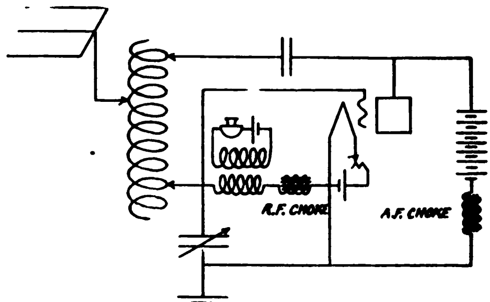


Fig. 23

smooth out the ripples by means of a filter circuit, though this will rarely be necessary. If noises are present in the received signals, a suitable filter circuit may be made for such a low power circuit as this, by constructing two coils each of 5000 turns of No. 36 D. C. C. magnet wire on a laminated soft iron core, having a 5/8 in. by 5/8 in. section and a length of 8 in., insulating each layer with thin white paper.

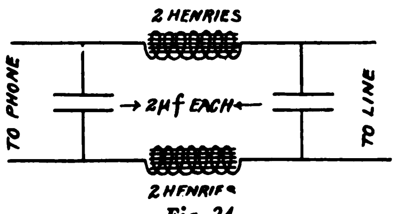


Fig. 24

These coils should be inserted in series with each leg of the supply circuit and cross-connected by two paper dielectric telephone condensers having a capacity of 2 micro-farads each, as shown in Fig. 24.

The antenna inductance as well as the plate coupling coil and grid input coil will be constructed as a single coil of

40 turns of No. 14 bare copper wire on a Bakelite or Micarta tube 5 in. in diameter and 6 in. in length. This tube should, preferably, have a 1/8 in. wall, though a thinner wall may be used with equal success if care is taken. The tube should be mounted in a lathe, and a spiral groove having a pitch of 1/8 in. should be cut to within ½ in. of each end. This will net a 5 in. winding space into which it will be possible to wind the required 40 turns. Every other turn should be tapped as shown in Fig. 25, care being taken in soldering the taps, which may be made of strips of light shim brass, in order to prevent either solder or flux from short

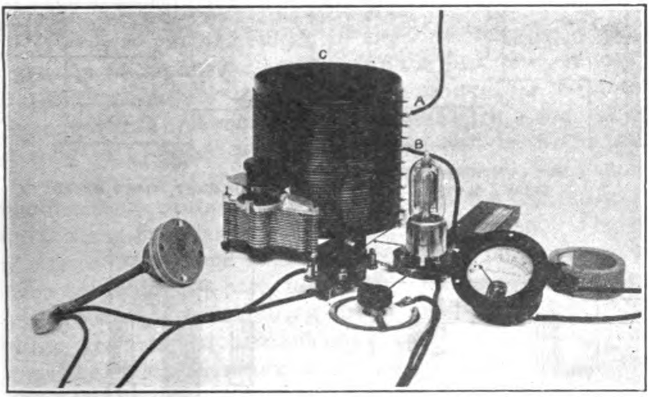


Fig. 25. View of 1/8 Watt Phone Circuit. This circuit utilizes a single receiving tube as an oscillator and can be operated entirely from five blocks of 22 volt B batteries in series for the plate supply and a 6 volt storage battery for heating the filament.

circuiting the turns. The taps should be soldered in place as the respective turns of wire are placed on the tube, and if care is exercised in this particular, no trouble from the sources mentioned should result.

As shown in Fig. 25, the radio-frequency choke coil consists of a 250 turn honey-comb.

The condenser inserted in the circuit between the coupling tap and the plate of Fig. 14 is an ordinary paper dielectric telephone condenser having a capacity of ½ micro-farad. In a low voltage circuit like the one under consideration, a smaller capacity is not recommended.

The variable condenser of Fig. 25, is of the type commonly used with receiving equipment and should have a capacity of approximately 0.001 micro-farad.

The milliammeter with a scale reading to 30 milliamperes, the vacuum tube and its receptacle, and the filament rheostat are standard equipment needing no detailed description.

Fig. 26 gives the details of the modulation transformer.

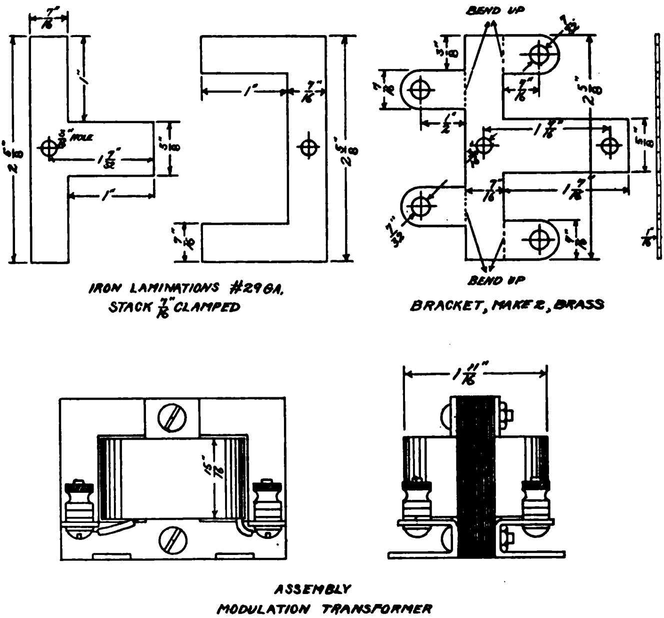


Fig. 26. Assembly of Modulation Transformer

Coil data: Primary, 150 turns of No. 28 enamel insulated wire in three layers. This should be wound upon a 15/16" mandrel and over 3 wraps of 5 mil fish paper. Secondary, 4000 turns No. 40 enamel insulated wire in 28 layers of 140 turns per layer. Layers should be insulated from each other with thin paper, and primary, from secondary with three wraps of 5 mil fish paper. Whole coil should be impregnated in paraffin after winding. This will result in a coil 1 11/16 in. in diameter and 15/16 in. wide which will fit the core detailed in Fig. 26 above.

It will be observed by referring to Fig. 14 that a grid leak is placed in the circuit between the grid and filament. The use of a grid leak is imperative in transmitting circuits and

care must be exercised in selecting the correct value. For Western Electric tubes of the type shown in Fig. 25, the grid leak resistance value should be approximately 10,000 ohms. Such resistances are easily obtained from stock at very little expense. In case the reader desires to construct one, the necessary details will be found in Fig. 27. Another alternative is to fill a glass tube 5 inches in length and having an inside diameter of 3/32 inch with pure lampblack, packing it lightly in the course of filling, and sealing the ends with brass plugs. The measured resistance of such a unit is approximately 10,000 ohms.

In Fig. 23, the resistance of the modulation transformer secondary is utilized as the grid leak.

By way of explanation to the experimenter who is operating a vacuum tube transmitter for the first time, it may be stated that more or less patience is required. A number of factors which influence the operation of such apparatus may not be in evidence physically. This will be found to be the case especially in a low power equipment. For example, the mere substitution of another tube for the one in use will turn what is apparently a failure, into success. The constants of the antenna seriously affect the operation of vacuum tube transmitters—particularly, the resistance. It is a good plan to study a transmitting circuit involving low powers by using an artificial antenna consisting of a small variable capacity and a resistance of 3 to 10 ohms, in series, across the antenna and ground connections.

Operation of the One-eighth Watt Phone Set

Place the artificial antenna circuit between the tap A, Fig. 25, and the ground connection (negative side of plate supply is grounded on this particular case) and cut out all resistance in dummy circuit. Manipulate filament rheostat until filament reaches correct temperature and cut in plate supply current. Select an arbitrary position for the plate tap B, Fig. 25, about half way between antenna tap and the lower connection to the variable inductance. The milliammeter will indicate a current of approximately 12 milliamperes flowing to the plate. Next, adjust the variable capacity and observe the pointer on the plate current milliammeter. It will show an increase or decrease in deflection when the limiting capacity is reached.

Oscillations will start on one side of this point of limiting capacity, depending upon the initial setting of the condenser. As this circuit contains no antenna ammeter, it will be necessary to resort to some other method of determining when the circuit is oscillating. If the circuit is oscillating properly and the antenna tap A, Fig. 25, is touched with the finger the milliammeter pointer will be displaced.

Assuming that the circuit is oscillating, we will next turn our attention to its adjustment. The "cut and try" method with a small previously calibrated receiving circuit may be used, but, the more expeditious and more accurate manner

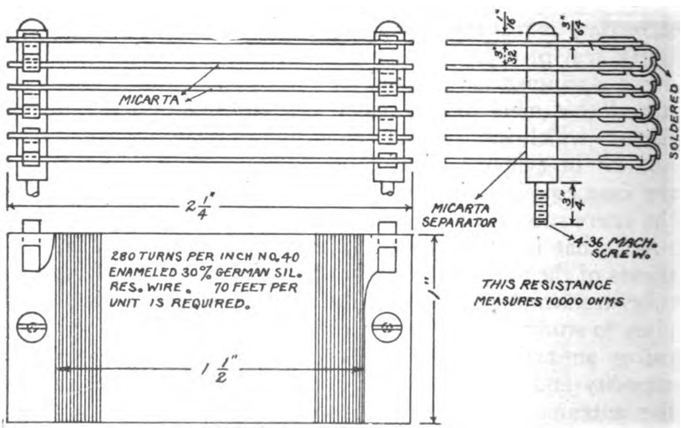


Fig. 27. Details of 10,000 Ohm Grid Leak

of tuning with a wavemeter should be used for best results. In this connection, any ordinary wavemeter having a current-squared meter or other equally sensitive indicating device may be employed. The procedure is not unlike that of tuning an ordinary spark transmitter, i. e., by coupling the loop of the wavemeter to the variable inductance C, Fig. 25, and adjusting A, B, and the variable capacity until the desired wavelength is obtained.

Up to the present time, we have been using the artificial antenna with practically no resistance in the circuit, and it may have been observed that as the resonance point was reached in the adjustment of the wavemeter, the circuit suddenly failed to oscillate. Gradually cut in resistance in

the artificial circuit (two rheostats like the one shown in Fig. 25, in series may be used), and follow up this operation with a corresponding adjustment of the taps A, and B, and the variable capacity, and note that the wavemeter does not seriously influence the oscillating quality of the circuit as heretofore.

Study the circuit in this manner and when a sufficient knowledge of its operating characteristics is obtained and when good stable oscillations are produced with 6 to 10 ohms of resistance in the circuit, replace the artificial circuit with a regular antenna. (It must be remembered, here, that 6 to 10 ohms of resistance is the form recommended above, is equivalent of 10 to 15 ohms of high-frequency resistance.)

As previously stated, the upper limit of operating frequency is governed primarily by the resistance, and often, the failure of a given circuit to oscillate may be traced to some object which introduces resistance into the circuit. Among these may be classed: leaky insulators, metal structures in the vicinity of the antenna, trees, and in fact anything that may introduce the condition of an imperfect dielectric in the vicinity of the antenna.

The use of a counterpoise is one of the best means of lowering the resistance of an antenna. The advantage of a low resistance antenna may be realized by a moment's thought to the following: The power circulating in the radiating system is, in general terms, equivalent to the product of the current squared times the resistance. Assuming in Fig. 14 that the resistance of the variable inductance plus that of the variable condenser is 2 ohms, and that of the antenna is 8 ohms, the total is 10 ohms. Now, assume that by using a counterpoise, the antenna resistance may be decreased to 4 ohms, the total will be 6 ohms. If the antenna current in the first case was 1 ampere, it would be approximately 1.7 ampere in the second. The result would be an output of 17.34 watts in the second case as compared to 10 in the first, and this, by halving the antenna resistance.

Up to the present time, the attention of the reader has been confined to a small assemblage of equipment constituting what might be termed a three mile set.

The Design and Construction of Inexpensive Five Watt Radio-Phone

Fig. 11 illustrates a circuit previously explained, wherein one 5 watt tube is used with a Hartley circuit as an oscillator, and another similar tube is used as a power modulator. This circuit will be used in the development of the 5 watt set, shown in Fig. 28, and, as will be seen by referring to this figure, several pieces of apparatus, the construction of which was explained heretofore, will be utilized.

This apparatus includes the variable inductance, the grid leak, modulation transformer, and the 250 turn honey-comb (in center of figure and back of the vacuum tube).

The factors governing the design of this experimental set may be stated as follows:

1. A source of direct current having an e.m.f. of 350 volts must be used. No details will be considered now as to the matter of obtaining this. It may, however, be obtained from a direct current generator, or from rectified alternating current in a manner to which the readers' attention will be called later.

2. The apparatus will be designed to operate at wavelengths between 200 and 375 meters.

3. It is assumed here, also, that the builder contemplates using this apparatus in connection with a small antenna, the limiting capacities of which will be found noted among the factors governing the design of the ⅛ watt set.

In view of the greater potential used in the operation of the 5 watt tubes, two ½ micro-farad paper dielectric telephone condensers must be used in series in the plate coupling lead to the variable inductance. It must be remembered that condensers of the type suggested above, are used to promote economy only. If, the constructor desires, he may use any other type of condenser capable of withstanding the impressed e.m.f. and having a capacity not less than 0.01 micro-farad.

The grid condenser upon which the grid leak resistance is mounted (Fig. 28) consists of three pieces of copper foil 2 by 3 in., separated by thin mica and mounted within a small wooden base.

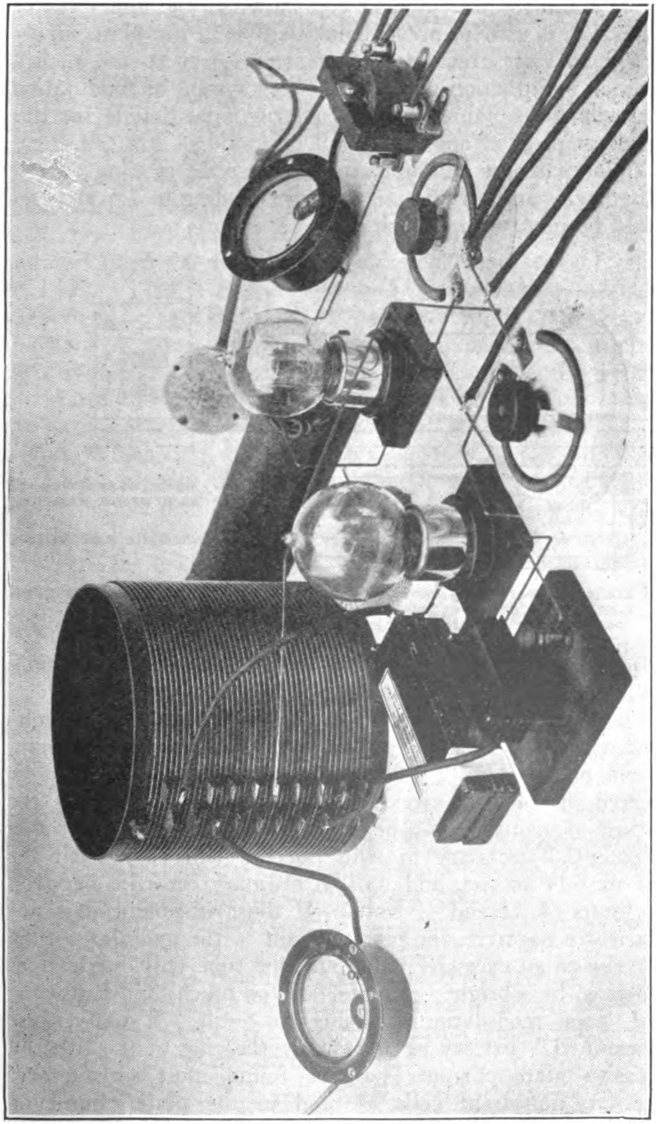


Fig. 28

The audio-frequency choke coil shown in the upper center of Fig. 28, is used to prevent fluctuations in the plate supply current at voice frequencies. It is necessary to use such a device in conjunction with the Heising system of modulation as previously explained. Full constructional details for this important piece of apparatus will be found in Fig. 29.

A plate current milliammeter with a scale reading to 150 milliamperes and a radiation ammeter reading to 1.5 amperes should be used with this circuit.

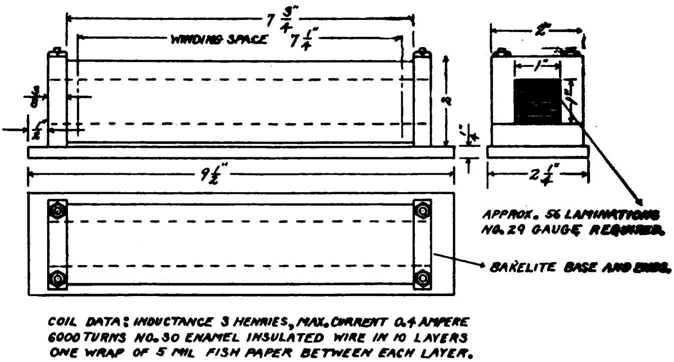


Fig. 29. Construction Details of Audio-Frequency Choke Coil

The battery of Fig. 11 represents the source of high voltage for the plates, and it is shown as such for conventional reasons only. The "C" battery of the same figure must be inserted in the grid circuit of the modulator tube for the purpose of maintaining a negative grid potential. The value of potential necessary for this purpose will vary with the type of tube in use, and will in ordinary cases lie between the limits of 22 and 40 volts. If the grid potential is not sufficiently negative, the plate current to the modulator tube will rise to an excessive value and the tube will overheat as evidenced by a bright red plate. If too much "C" battery is used, poor modulation is liable to result. Usually, just sufficient "C" battery to prevent overheating of the tube by excessive plate currents will be found most satisfactory. Ordinary flashlight cells as used in the plate circuit of receiving apparatus will suffice for this purpose.

Adjustment, Tuning and Operation of the Experimental Five Watt Set

By referring to Fig. 28, the reader will observe that there are one fixed, and three variable connections to the inductance. The fixed connection divides the inductance into two unequal parts: the lower seventeen turns constituting the input inductance and the twenty-three above, the output inductance. Inasmuch as this fixed connection is tied to earth (see Fig. 11), it represents a point of zero potential, and the potential impulses on either side are out of phase by 180°. This is a necessary condition in the operation of vacuum tube oscillators. The necessary input coupling and resultant impressed grid potential are obtained by altering the position of the lower variable connection on the portion the inductance below the fixed connection. The position of the antenna lead determines the period of oscillation of the circuit, which may, however, be influenced by any alteration in the position of the plate coupling tap represented by the upper flexible lead in Fig. 28.

In the initial tuning and study of this circuit, the reader is urged to make use of an artificial antenna wherein the phenomena attending the introduction of resistance into the oscillating circuit may be studied in detail.

Tuning this circuit with a wavemeter is recommended, though the ease with which the various adjustments may be made and the ease with which the circuit oscillates admits of other methods.

The following procedure is outlined for the experimenter in using the circuit for the first time (see Fig. 28):

1. Disconnect antenna lead to radiation ammeter and substitute an artificial antenna consisting of a small variable capacity, 0.001 micro-farad, and a small variable resistance device, 10 ohms, and cut out all resistance.
2. Place the various leads to the inductance approximately as shown in Fig. 28.
3. Remove the modulator tube from the circuit temporarily, and by means of the filament rheostat adjust the oscillator tube filament to the correct operating temperature.
4. Cut in the plate current supply.

Before the circuit is properly adjusted the plate current milliammeter may indicate that upwards of 100 milliamperes

is flowing, and there may be no deflection of the radiation ammeter pointer. If the grid input tap (lower one in Fig. 28) is shifted, the plate current should fall off rapidly until only 30 or 40 milliamperes flow, when oscillations should be in evidence by a deflection of the radiation ammeter pointer. To obtain a maximum output current, it will now be necessary to shift the plate coupling tap until the correct position is found. Note here, that the output current (radiation) increases as the e.m.f. to the plate is increased and that the radiation increases also as the filament temperature is increased to a certain point, beyond which no further increase in the filament temperature without a corresponding increase in the plate potential, will increase the output current.

Thus far, the oscillating circuit has been one containing little resistance and abnormal output currents may have been observed.

Gradually, cut in resistance in the artificial antenna circuit and follow up each change with corresponding circuit adjustments. The radiation will fall to a fraction of its former value. After the circuit has been studied in this manner, substitute the real antenna for the artificial one, and when the circuit is readjusted for this change, cut out the supply of high voltage to the plate, and place the modulator tube in its receptacle. Adjust both filaments to the correct temperature and again close the plate supply circuit.

The circuit is now ready for use, except for the adjustment of the "C" battery and the regulation of the microphone battery circuit.

CHAPTER IV

THE DESIGN AND CONSTRUCTION OF A 10 WATT C. W. TRANSMITTER, I. C. W. TRANSMITTER AND PHONE SET USING DIRECT CURRENT

IN conformity with the policy adopted in the preceding chapter of stating the conditions affecting the design and construction of apparatus under consideration, the following statements are made with reference to the subject matter:

1. A Hartley oscillating circuit wherein two 5 watt tubes are employed as oscillators, will be used in conjunction with the Heising system of modulation employing two similar tubes as modulators.
2. With a small antenna, the apparatus must function at frequencies corresponding to wavelengths between 200 and 375 meters.
3. The various integral pieces of apparatus, except the radiating system, sources of power supply and attendant filter and rectifier systems must be so mounted as to comprise a complete unit.
4. An efficient self contained switching arrangement must be provided in order that the operator may transmit signals of any of the following characteristics at will: viz, C. W., I. C. W., and phone.
5. Efficiency in operation combined with ruggedness in construction will be considered as of paramount importance.

Figs. 30, 31, and 32 show three views of the completed apparatus. Fig. 33 is a schematic diagram of the circuit. It will be observed by reference to the figures that much of the apparatus was obtained from the market; for example, the indicating instruments, filament rheostats, receptacles, modulation transformer, choke coils, and switches. The constructor will do well in following this practice, since, in

most cases, it will be the more economical. However, full constructional details will be found elsewhere in the manual for much of the above mentioned apparatus.

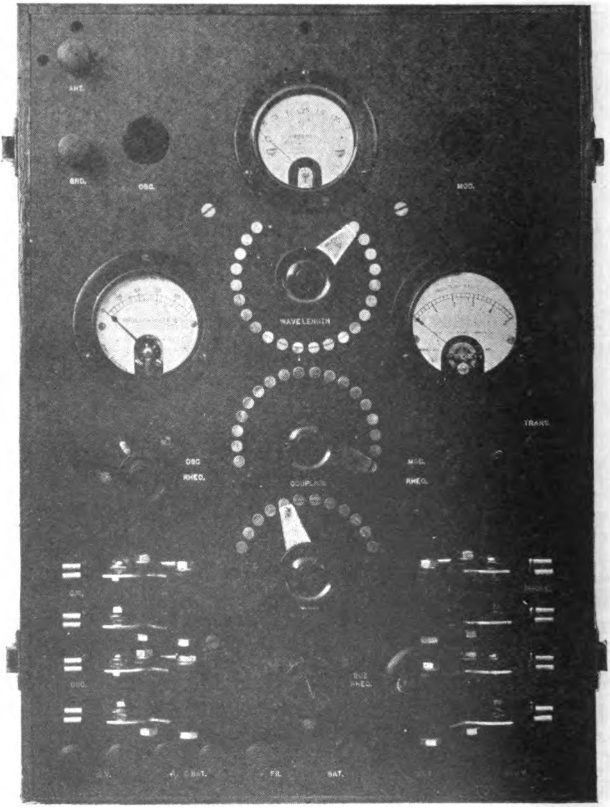


Fig. 30. Front View of 10-Watt Phone Set.

In the construction of this unit, recourse will be given first to apparatus comprising the basic electrical parts of the circuit—since the arrangement of these parts in the circuit depends to a great extent upon the constructor's adherence to the specifications given. In most cases, considerable tolerance is allowed.

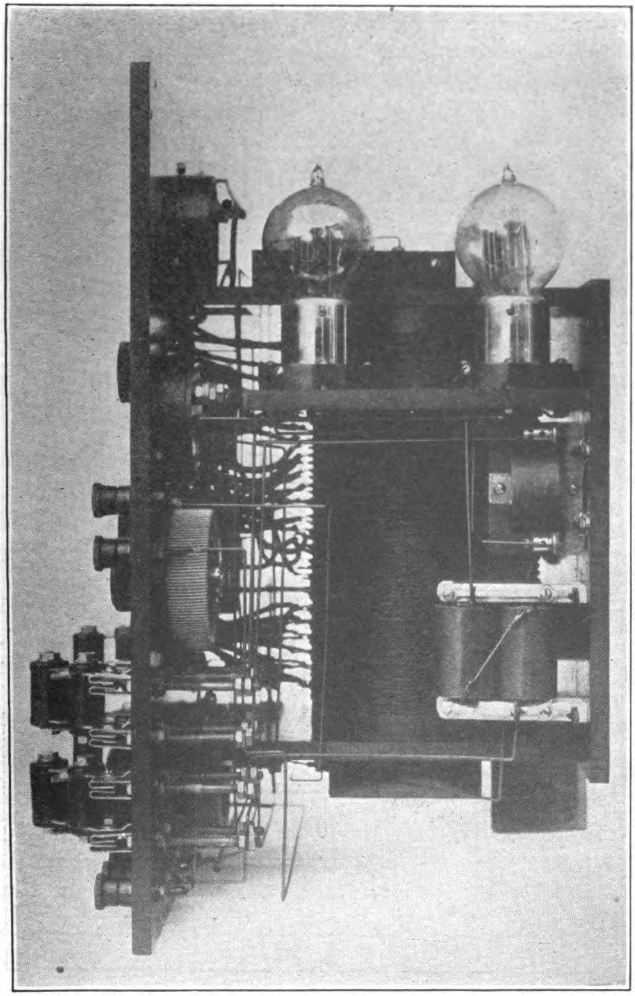


Fig. 31. Right Profile of 10-Watt Set, Showing Location of Modulation Transformer and Audio-Frequency Choke Coil. Note location of Key Condenser Under Lower Sub-panel.

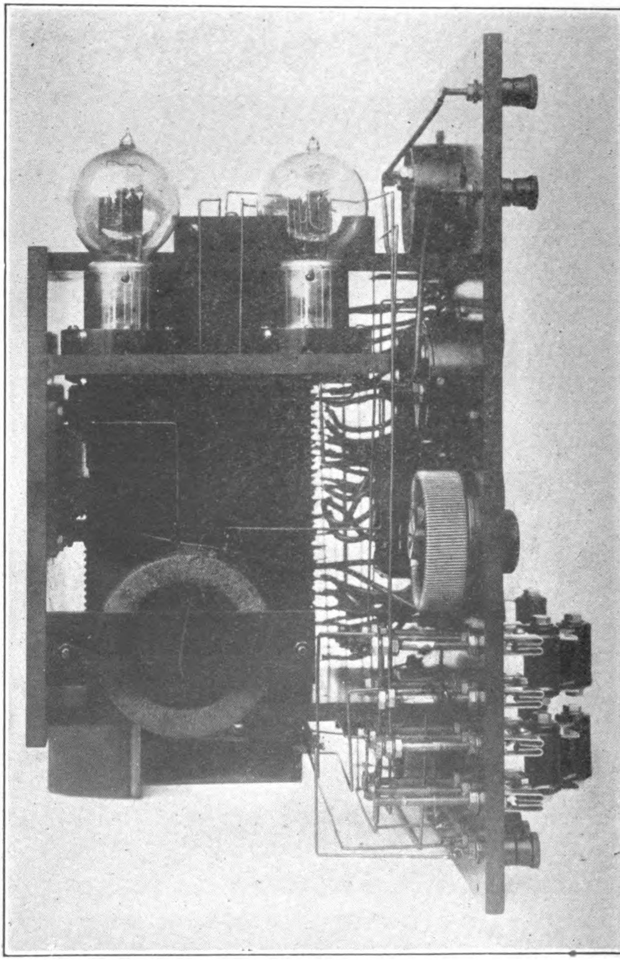


Fig. 32. Left Profile of 10-Watt Set, Showing Location of Radio-Frequency Choke Coil and Plate Series Condenser.

The details of the condenser inserted in the circuit between the plate and coupling tap on the variable inductance are shown in Fig. 34. As will be seen by reference to this figure, the condenser is merely an ordinary mica dielectric

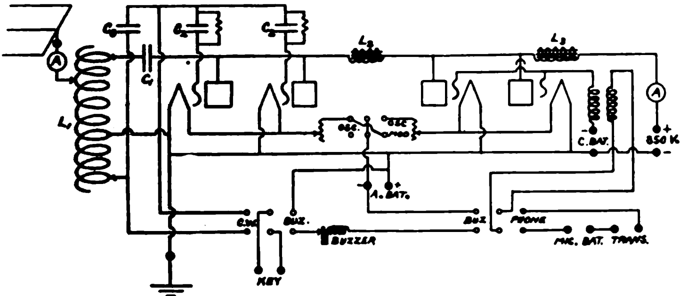


Fig. 33. Diagram of 10-Watt Phone Set.

device having a capacity of approximately 0.01 micro-farad. It is mounted as in Fig. 32 upon the inside surface of the backboard under the oscillator tube sub-panel.

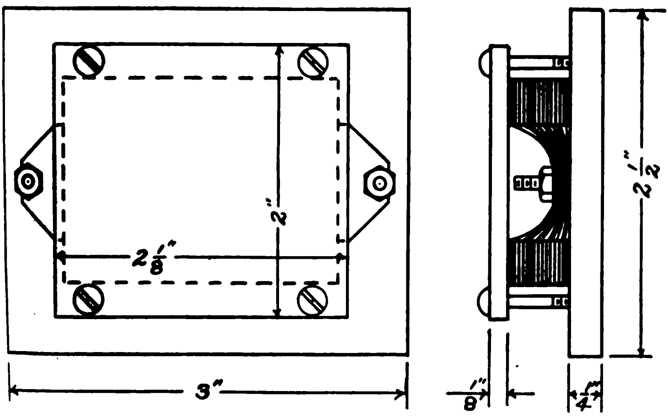


Fig. 34. Details of Condenser in Circuit Between Plate and Coupling Tap. Capacity, 0.01 mf., 50 pieces copper foil 1.75 x 1.25 in. between 51 pieces 5 mil ruby mica 2 x 1.5 in.

The radio-frequency choke coil shown in the same figure consists of a 250 turn honeycomb mounted upon the bracket which is detailed in Fig. 35.

The mounting for the modulation transformer and radio-frequency choke coil is shown in Fig. 31. Complete details for the construction of the modulation transformer are given in Fig. 26. If the reader desires to construct an audio frequency choke to take the place of the one shown in Fig. 31, he may do so by following the details of Fig. 29

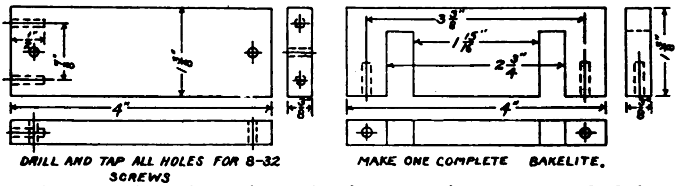


Fig. 35. Dimensions of Bracket for Mounting Honeycomb Coil.

The attention of the reader will now be turned to the grid circuit in Fig. 33. It will be observed that this is a branched circuit consisting of three small capacities and two large resistances. The individual grid condensers should have a capacity of approximately 0.0005 micro-farad, and should be shunted by a suitable grid leak resistance. For Western

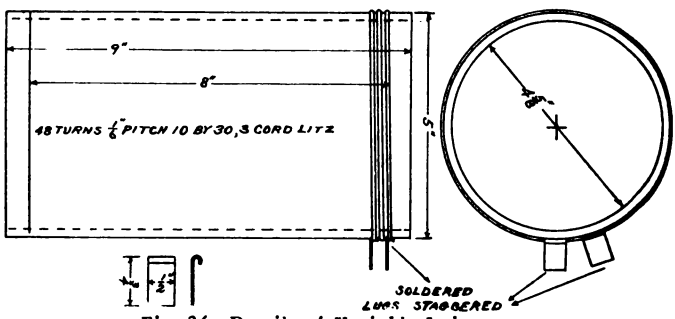


Fig. 36. Details of Variable Inductance.

Electric Co. oxide-coated filament tubes, this resistance should have a value of about 10,000 ohms. Some manufacturers recommend that with their tubes, the capacity-grid-leak-resistance system comprise a resistance of 5000 ohms in conjunction with a capacity of 0.002 micro-farad.

Three sheets of copper foil 2 by 3 inches separated with thin mica may be used with the grid leak shown in Fig. 27 for each of the oscillator tubes of Fig. 33.

The third condenser in this system is one of similar construction. By manipulating the upper left hand switch of Fig. 30, a small telegraph key is shunted across this condenser for the transmission of C. W. signals. When thrown to the opposite side, this switch inserts the key in the buzzer circuit for the transmission of I. C. W. signals. In this latter position, the two disengaged switch points must be short-circuited to cut the key condenser out of circuit. It may be well to point out here that the resistance of the key condenser, as measured by means of a megger, should be infinity. If this resistance is of any finite value, in all probability the circuit will oscillate with the key in the released position. A leaky key will often cause the same trouble. This condenser, as well as the grid condensers and leaks, are mounted atop the upper horizontal panel of Fig. 32.

Two 2½ ohm rheostats and one 7 ohm rheostat serve to control the modulator and oscillator filaments and the buzzer, respectively. An added refinement, though an unnecesssary one if good tubes are used, would be the introduction of a separate rheostat for each filament.

The variable inductance, which is supported between the upper and lower sub-panels of Fig. 31, consists of a Bakelite tube (see Fig. 36 for details) 9 in. long and 5 in. in diameter. It is threaded for 8 in. of its length, leaving a ½ in. margin on each end and wound with 48 turns of 10 by No. 30 enamel insulated wire twisted three cord. A slightly better design of Litz for use with alternating currents of the frequencies corresponding to wavelengths between 200 and 375 meters, could be developed with No. 38 enameled wire. The increased difficulties resulting from the use of such small wire, particularly in regard to making the taps, soldering, etc., would not warrant its use, however. Taps should be provided as indicated in the accompanying table. In making connections to this type of conductor, considerable time and care is required.

The small brass lugs shown in Fig. 36 should be soldered to the Litz in the following manner as the respective turns are wound upon the tube: Clamp a small electric soldering iron between the jaws of a bench vise to steady same. The iron should be previously tinned in order to hold a small globule of solder on the flat part of the point. Immerse the conductor in this hot solder at the point to be tapped, add-

ing solder if necessary. Holding the wire in this position, scrape carefully with a sharp knife. The enamel, now softened and partially charred by the heat, will float to the surface of the globule and can be removed with ease. Using

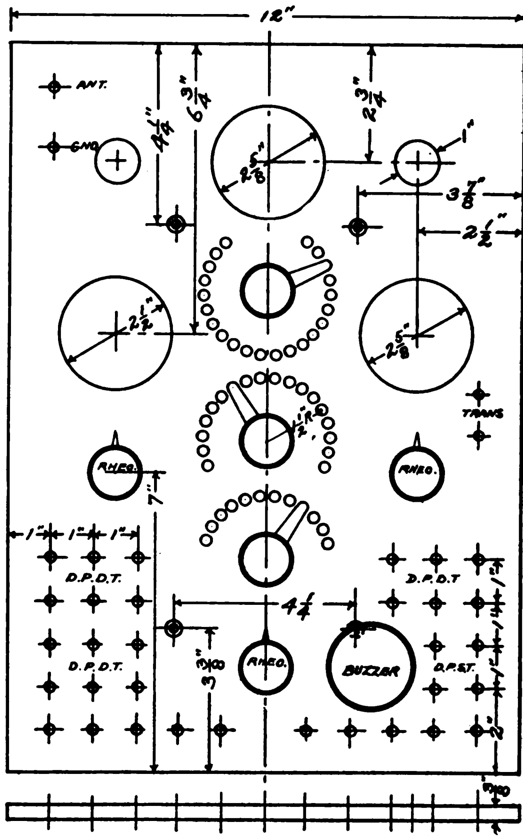


Fig. 37. Main Panel and Backboard Layout.

a small piece of solid wire solder as an instrument, apply a small amount of good anti-corrosive soldering paste to the heated section of the conductor, and, if same is properly cleaned as suggested above, the whole should become a solid mass at this point, to which the small brass lugs of Fig. 36

may be soldered quite easily. Care and practice will expedite the whole process of soldering a tap to about three minutes.

In Fig. 30, it will be observed that three multi-contact tuning switches are provided; the points, of course, are connected to the lugs on the inductance in accordance with the table, Fig. 37, and the switch arms, to the antenna (via radiation ammeter), to the plate condenser, and to the key condenser, respectively, as shown in Fig. 33. No details are

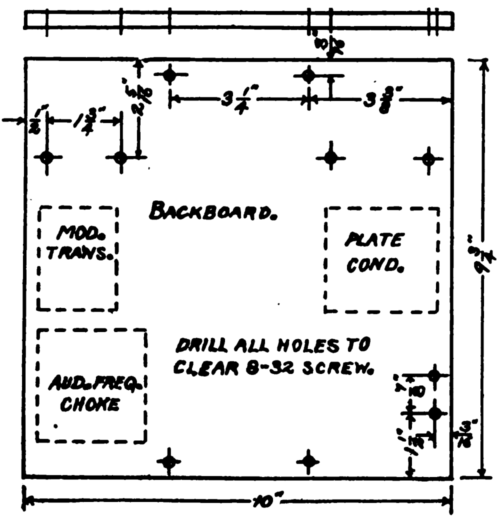


Fig. 38. Layout of Backboard.

given for these multi-contact switches, nor the changeover switches shown in the same figure.

The buzzer for interrupting the continuous waves into small groups at audio frequency, is shown in the lower right corner of Fig. 30, and its control rheostat is in the lower center of the same figure.

The indicating instruments must be selected with due consideration to the type of tubes that will ultimately be used. In the original apparatus herein described, the author used a milliammeter with a scale reading to 100, which restricted its use to the measurement of the current to the oscillator tubes only.

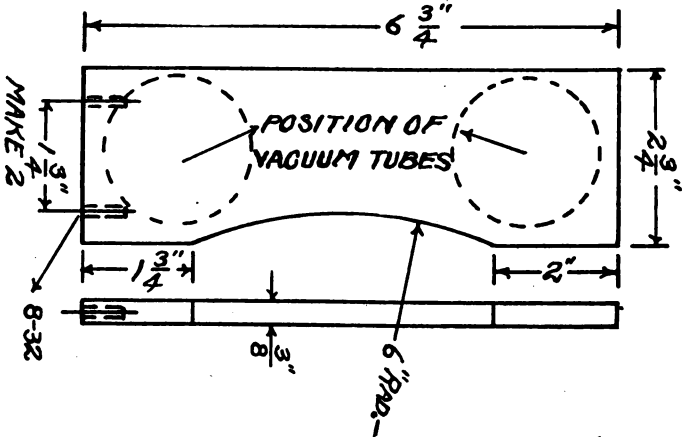


Fig. 38a. Layout of Sub-panel

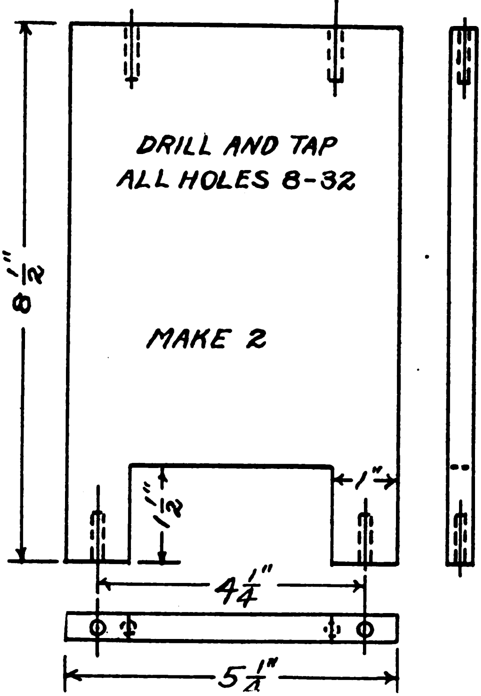


Fig. 38b. Layout of Sub-panel

GRID TAPS (A)	TURNS (B)	LUGS (C)	COUPLING TAPS (D)	WAVELENGTH TAPS (E)
	1	—		22
	2			
	3	—		21
	4			
	5	—		20
	6			
	7	—		19
	8			
	9	—		18
	10			
	11	—		17
	12	—	18	
	13	—	17	16
	14	—	16	
	15	—	15	15
	16	—	14	14
	17	—	13	13
	18	—	12	12
	19	—	11	11
	20	—	10	10
	21	—	9	9
	22	—	8	8
	23	—	7	7
	24	—	6	6
	25	—	5	5
	26	—	4	4
	27	—	3	3
	28	—	2	2
	29	—	1	1
	30	—	MID POINT	
	31			
	32			
	33			
	34			
	35			
1	36	—		
2	37	—		
3	38	—		
4	39	—		
5	40	—		
6	41	—		
7	42	—		
8	43	—		
9	44	—		
10	45	—		
11	46	—		
	47			
12	48	—		

"WAVELENGTH" SWITCH		"COUPLING" SWITCH	"GRID" SWITCH
22			
21			
20			
19			
18		18	
17		17	
16		16	
15	—	15	
14	—	14	
13	—	13	
12	—	12	12
11	—	11	11
10	—	10	10
9	—	9	9
8	—	8	8
7	—	7	7
6	—	6	6
5	—	5	5
4	—	4	4
3	—	3	3
2	—	2	2
1	—	1	1

Table Showing Grid Taps and Switch Connections. In Table to Left Column B Indicates the 48 Turns of Litz, C Shows Position of Lugs, A, D and E, Connections of Various Switch Points. The "Coupling" and "Wavelength" Switches Have 15 Common Connections as Indicated by the Dashes Between Columns One and Two of Right Hand Table.

Western Electric Co. tubes have been used at all times with this apparatus, which made the use of a 5 ampere filament ammeter possible.

In constructing this apparatus for use with any type of 5 watt tube on the market at the present time, it is suggested that a milliammeter reading to 300 milliamperes be used in the plate circuit, that an ammeter reading to 10 amperes be used in the filament circuit, and that a radiation ammeter reading to 1.5 to 2 amperes be used in the antenna lead. As a matter of information, in connection with this latter instrument, the radiation, using two 5 watt tubes as oscillators, will vary from 1 to 1.3 amperes at the most efficient wavelength.

Details for the construction of the various panels and sub-panels will be found in Figs. 37 and 38. These panels are constructed of 3/8 in. Bakelite sheet. The details of the cabinet for this apparatus are left to the constructor. It may be stated, however, that one having inside dimensions not smaller than 11 by 16 by 9¼ inches deep is recommended.

CHAPTER V

DESIGN AND CONSTRUCTION OF 10 WATT C. W. TRANSMITTER FOR USE ON A. C.

THE rating of ten watts is conservative for the apparatus that we shall consider in the present chapter. It might more appropriately be defined as a combination operating on alternating current and employing two 5 watt tubes when both sides of the cycle are utilized by pre-rectification and four 5 watt tubes when self rectification is used. Indeed, such combinations, when using the very rugged transmitting tubes of today, often put three times their rated output energy into the radiating system.

The chapter will be devoted to such apparatus as will be used for the transmission of telegraphic signals only; it being understood, however, that with slight modification the arrangement may be converted into one for transmitting voice signals as well.

Three circuits present themselves: one in which self-rectification is resorted to (see Fig. 39); one in which the high voltage alternating current is previously rectified by means of two rectifier tubes; and another in which the inexpensive electrolytic rectifier supplants the tubes of the second circuit. The latter circuits are illustrated in Fig. 40.

Fig. 15 represents a circuit in which one tube only is employed on alternating current, and in view of the unilateral conductivity which is an inherent factor in the physics of the thermionic valve, the tube is idle during the portion of the cycle when the plate is negative. In other words, the same effect is produced insofar as the operation of the circuit is concerned as would be produced by substituting a pulsating direct current supply to the plate in lieu of the alternating supply. The emitted signals consist, therefore, of trains of radio frequency oscillations, the train fre-

quency corresponding to that of the alternating supply to the plate. In Fig. 16, two tubes are employed and both halves of the cycle supply a useful current to the plates of the respective tubes. Fig. 41 shows the oscillating output current graphs of the two circuits. As will be seen, Fig. 39 is merely a modification of Fig. 16.

The transformer for supplying the high voltage to the plates and the filament heating current will be considered first, and in developing this piece of apparatus we shall go somewhat beyond a device for this circuit alone, in that it will be designed with the idea of using it for furnishing a

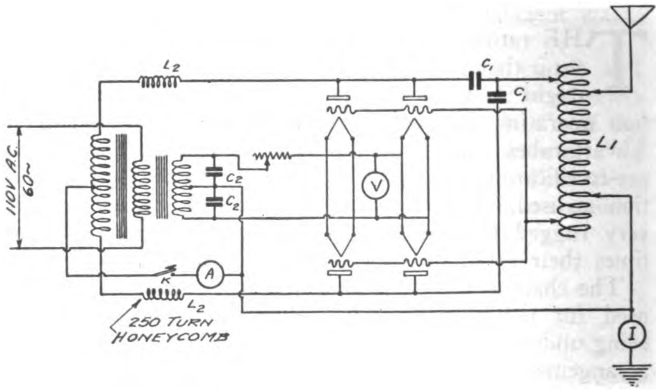


Fig. 39. Self Rectifying Circuit Using Four 5 Watt Tubes

filament current for rectifier tubes also. This additional winding is quite easily provided and the possibility of a future use for it warrants the small amount of additional labor required to make same.

Upon one of the long legs of a laminated silicon steel core having a 1½ by 1½ in. section and a 1½ by 4 in. window wind a primary for 116 volts of 220 turns of No. 14 D.C.C. magnet wire in four layers, insulating same from the core with six wraps of 5 mil fish paper and each layer from the next with one wrap of the same material. Bring out three additional taps at 193, 200 and 210 turns for supplementary voltage control. Over this coil place six wraps of the 5 mil fish paper and wind a secondary consisting of 3000 turns of No. 28 enamel insulated magnet wire, insulating each layer from the adjacent one with a single wrap of thin

paraffin paper. Tap the secondary at the center and at 1100 turns on each side of the center. This will provide a 700 and a 500 volt winding on each side of the midtap, allowing for a conservative magnetic leakage factor and a nominal voltage drop at the rated output.

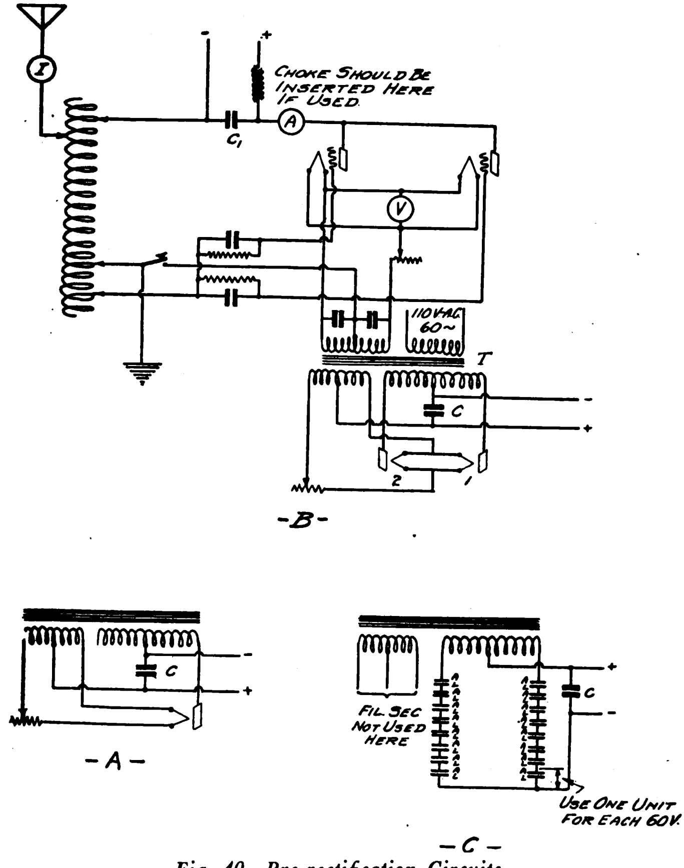


Fig. 40. Pre-rectification Circuits

On the other long leg of the core wind two coils of 24 turns each of No. 14 D.C.C. magnet wire tapping each coil at the center, thus providing a midtap for the return filament to grid connection to eliminate the hum which would

otherwise be present in the received signal because of a grid to filament connection to either end of this winding. To facilitate the matter of making connections to the various taps a suitable panel and arrangement of binding posts should be provided for this transformer.

The variable inductance, L_1, Fig. 39, should consist of approximately 35 turns of 1/16 by ¼ in. edgewise wound copper tape or the equivalent in 3/16 in. outside diameter copper tubing. Solid copper wire (about No. 6) may be used instead of the above with a slightly appreciable increase in resistance for the total coil. Four clips should be provided with this inductance for making connections. Two blocking condensers, C_1, having a capacity not less than 0.002 microfarad each or a multiple condenser having a total capacity of 0.004 microfarad with a midtap must be used in the plate to inductance leads to prevent the short circuiting of the high voltage transformer secondary by the inductance, L_1.

The radio frequency chokes, L_2, consist of 250 turn honeycomb coils. The bypass condensers, C_2, for the filament secondary may conveniently consist of ½ microfarad telephone condensers.

The transmitting key should be placed at K, in series with the plate milliammeter which should have a scale reading to 300.

The most recent practice in transmitting tube circuits requires a voltmeter in the filament circuit to secure proper filament adjustment in place of the much used filament ammeter, and accordingly one is shown at V in Fig. 39. This instrument should have a scale reading to 12 volts.

The radiation ammeter in the ground lead may be of the hot wire or thermo element type with a 2.5 ampere scale.

In connection with the adjustment of this circuit, attention is invited to Chapter III wherein the required procedure and caution are considered in detail.

As previously mentioned, Fig. 40 illustrates a circuit in which pre-rectification of the alternating current source is employed. Let us first discuss pre-rectification by means of thermionic valves.

The simplest form of rectifier circuit is shown in Fig. 40-A. Here, a single tube allows a plate to filament current (inside the tube) to flow when the plate is positive and

permits of no flow when the plate is negative. It is of course positive during one-half of the cycle and negative during the other, and phenomena mentioned above results in a pulsating direct current supply to the capacity C of Fig. 40-A, charging one side of the condenser dielectric with positive charges and the other with negative changes. If the drain on the condenser C, resulting from a withdrawal of energy by the oscillator tubes is such as to completely discharge same during each cycle, the oscillating output of the radio energy circuit will be pulsating and an audio note corresponding in frequency to the supply to the rectifier tube will be in evidence at the receiving station. This low frequency note will be found objectionable. Notwithstanding this feature, the oscillator tubes cannot be worked at maximum output for they are idle during a large portion of the time.

Fig. 40-B shows a circuit in which two rectifier tubes are used. During the portion of the cycle when the plate of the first tube is positive, this tube supplies useful energy to the condenser C, and the second tube is idle because the plate is negative. During the other portion of the cycle, the plate of the second tube is positive and it supplies the useful energy to the capacity or *storage tank C.*

A moment's thought to what has been said will convince the reader that it is very desirable, then, to have as large a capacity as possible at C.

A two microfarad paper dielectric condenser, designed to withstand the impressed e.m.f. is ideal for this purpose, although one having as little as 0.25 microfarad capacity will suffice.

It should be observed here that the midtap of the high voltage secondary winding of the transformer in Fig. 40-B is the negative side of the direct current supply to the oscillating tube circuit and the center tap of the filament secondary is the positive side.

To further smooth out the pulsations it is recommended, though unnecessary for telegraph work, that a 2 or 3 henry choke be inserted in the positive leg of the rectifier output circuit. The necessary details for the construction of such a choke coil will be found in Chapter III.

The capacity C_1 of Fig. 40, is unnecessary if the above mentioned choke coil is not used in the rectifier output leads,

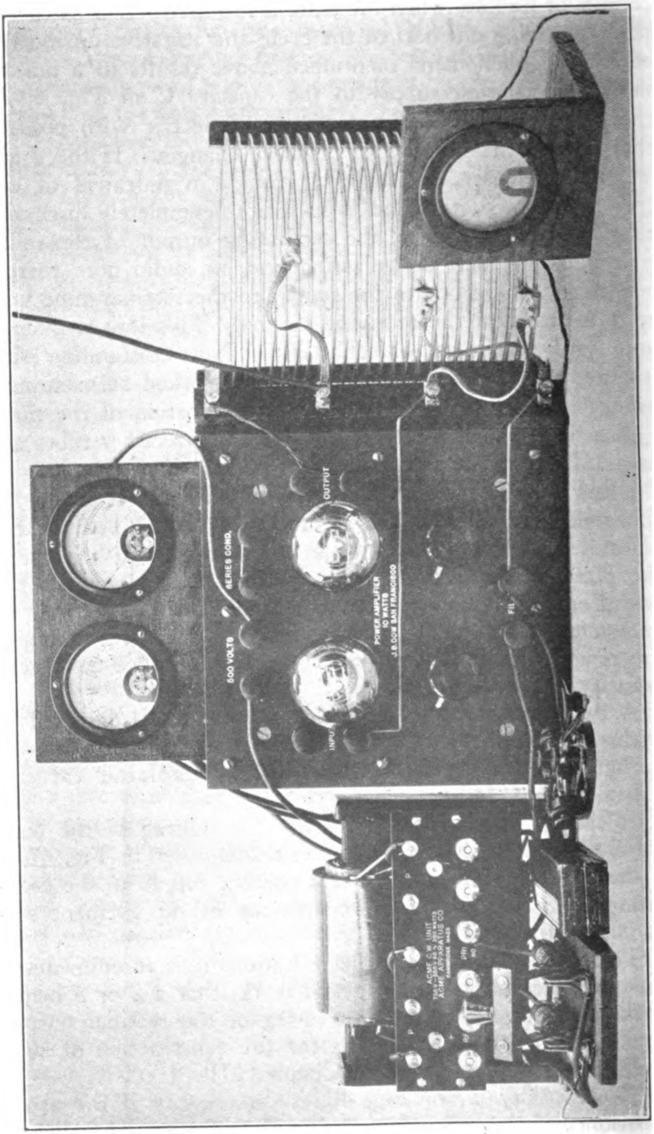


Fig. 42. Complete 10 Watt C. W. Transmitter Operating on Pre-rectified A. C.

but it must be inserted in the circuit in case the choke coil is used.

In case it is desired to use electrolytic rectification the circuit shown in Fig. 40-C may be used. Observe here, however, that the midtap of the high voltage secondary is the positive lead rather than the negative one as found in the case of the thermionic rectifiers above. Suitable electrolytic rectifier units may be constructed by placing one aluminum and one lead plate, each 1 in. by 1/16 in. by 5 in. in length (allowing for connection) in pint Mason fruit jars

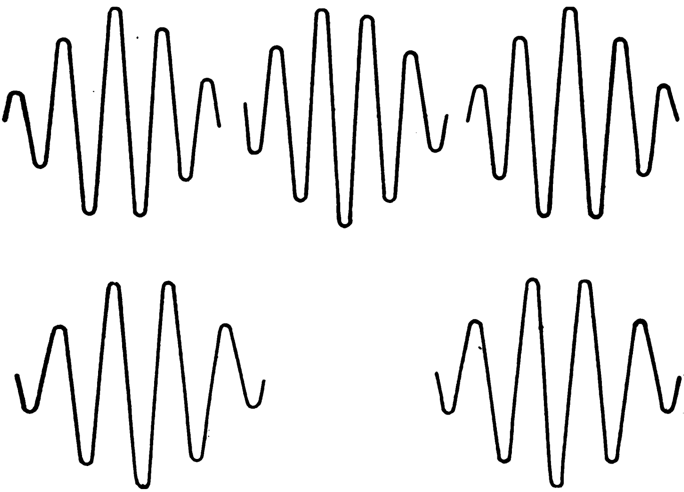


Fig. 41. Upper Drawing Shows Oscillating Current Output from Circuit of Fig. 15, and Lower from Circuit of Fig. 16. Only a few Oscillations per Train Are Shown.

three-quarters full of a saturated solution of sodium borate (borax) or ammonium phosphate. The plates should be immersed for about 3 in. of their length and should be separated from one another a distance of approximately 2 in. One of these units is required for each 60 volts to be rectified and if it is desired to rectify both sides of the cycle as shown in Fig. 40-C, twice this number of units are necessary. The aluminum plates must be *formed* before

the device is operative as a rectifier. This consists in depositing a white crystaline formation upon them. To do this, connect a 500 volt alternating current source to the plates of one unit, first immersing the jar for about two-thirds of its height in cool running water to maintain a constant temperature. One side of the high voltage secondary may be used for supplying the necessary 500. volts, although the transformer may get hot and may have to be operated intermittently to prevent overheating. The process of forming the plates requires approximately two hours and is complete when the aluminum plate sparks profusely over its surface. A condition may come about in the formation of the plates wherein the aluminum plate fails to spark after a reasonable time, in which case it will generally be found that the plate has become dark and covered with scabs. If this condition exists, begin the process all over again with a new plate, for it is a difficult task to clean such plates.

As was found to be the case with other systems of rectification, a choke coil inserted in the positive lead from the condenser, C, assists materially in smoothing the output for telephonic purposes.

In the circuit of Fig. 40 individual grid leaks and grid condensers should be used to bring about the required negative grid potential. A capacity of 0.002 microfarad shunted with a resistance of 5000 to 10,000 ohms will be found satisfactory.

CHAPTER VI

AN INEXPENSIVE 50-WATT C. W. TRANSMITTER

THE first thought of the average experimenter as to an inexpensive 50-watt C. W. transmitter may quite easily rest upon a motor generator involving an expenditure of $150 alone, or he might visualize an arrangement of apparatus consisting in part of two rectifying tubes at the modest price of $60.

With 60 cycle alternating current available, two circuits may quite easily be developed to eliminate both of the expensive combinations referred to above and at the same time provide an installation which will operate fully as satisfactorily as any that might be used involving the eliminated apparatus.

Fig. 46 illustrates a circuit employing a single 50-watt tube as an oscillation generator and using a source of high voltage alternating current pre-rectified by an arrangement of forty easily constructed rectifier units. The previous chapter dealt in part with the construction of such units.

The details of the transformer, T, Fig. 46, follow, and it might be added that the output of this transformer is sufficient to supply four 50-watt tubes or a combination of two 50-watt tubes and two rectifier tubes.

Upon one of the longer legs of a core having a 2 by 2 inch section and a 6 by 3 inch window, wind a primary coil of 175 turns of No. 11 or 12 S. C. C. wire in three layers, insulating the winding from the core with 8 wraps of 10 mil fish paper, and each layer from the next with one wrap of the same material. Tap the primary at the following turns for voltage control: 165, 169, and 173. Over the primary place 8 wraps of 10 mil fish paper. Next, wind two secondary sections to fit over this, of 2400 turns of No. 24 enamel insulated wire in 32 layers. The 5 mil fish paper

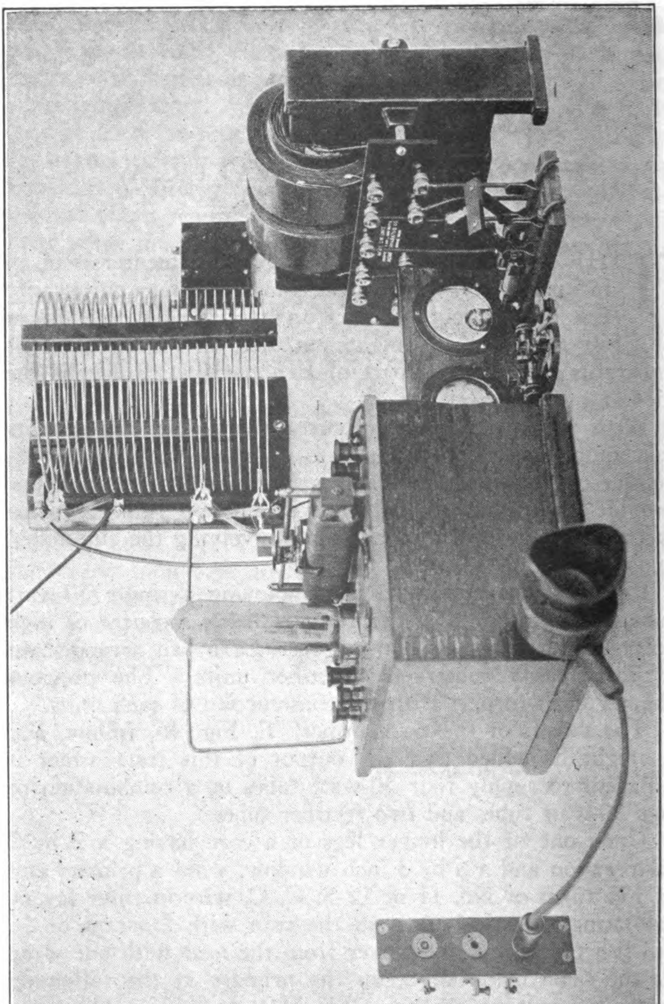


Fig. 44. 50 Watt C. W. Transmitter Using 50 Watt Combination Amplifier as an Oscillator

between each layer should be 2 in. wide and this will permit of a winding space of 1⅝ inches wide. Each section should be tapped at the 1600th turn and with the two sections connected in series with a midtap at the point of connection the output voltage will be approximately 935 or 1450 on each side of the midtap.

The filament heating secondaries should be wound upon the other long leg of the core over 8 wraps of 10 mil fish paper. These units should comprise two 22 turn coils of No.

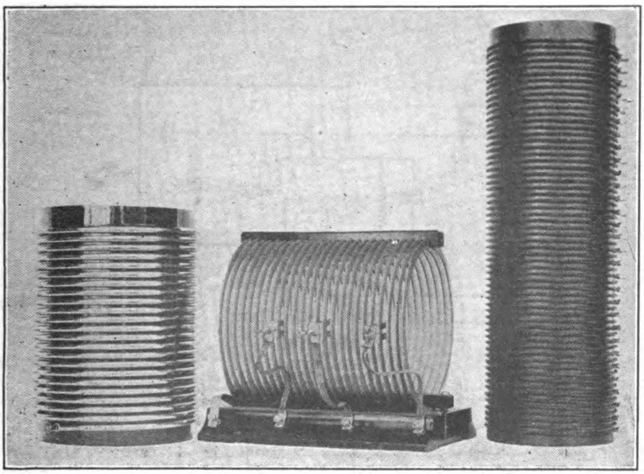


Fig. 45. Well Designed Types of Inductances

8 D. C. C. magnet wire in two layers with midtaps, and will provide ample current at a potential of 12 volts for the filaments of power and rectifier tubes.

Connection posts for all taps may be brought out to a suitable panel secured to the core structure.

The filter circuit, C_2 C_3 L_2, may be modified by the elimination of the choke L_2, and the capacity C_2, if it is not contemplated to control the output telephonically. The capacities C_2 and C_3 should be of the order of a microfarad and designed to withstand the maximum voltage used. The choke coil L_2 has been described in detail in a previous chapter.

It will be observed in Fig. 46 that the capacities C_1 and C_3 are apparently shunted and the total capacity is the sum total of the two. It is obvious, therefore, that C_1 may be eliminated if the filter circuit, or more pertinent the capacity C_3, is in such proximity to C_1 that the reactive effect of intervening conductors is negligible. If the filter circuit is appreciably distant from C_1, this condenser should have a capacity of approximately 0.01 microfarad. The details of such a condenser may be found in Fig. 34.

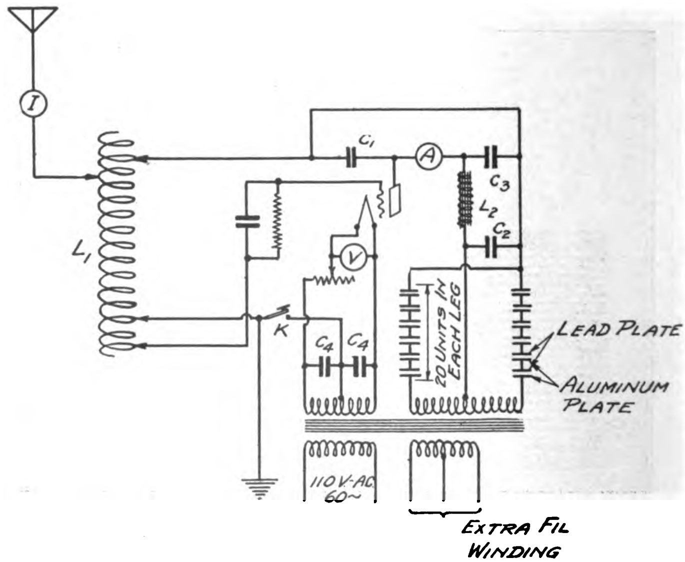


Fig. 46. Circuit Using One 50-Watt Tube as Oscillation Generator and Pre-rectified A. C. Power Supply

The filament heating secondary, Fig. 46, is bridged by two one microfarad paper telephone condensers, C_4, and the midpoint of this arrangement is connected to the midpoint of that secondary to the key K.

The voltmeter, V, in the circuit facilitates the adjustment of the filament and is recommended in lieu of an ammeter for this purpose.

The grid leak of Fig. 27 or an equivalent one of 5000 to 10,000 ohms should be used in conjunction with a small

capacity of 0.002 microfarad to obtain a sufficiently negative potential for efficient operation.

Fig. 45 shows three well designed types of inductances such as may be used at L_1. On the left is one constructed of ¼ inch O. D. copper tubing and manufactured by Heintz and Kohlmoos; the center one is the well known Radio Corporation device made up of edgewise wound copper strip, and on the right is one designed by the author for use in the

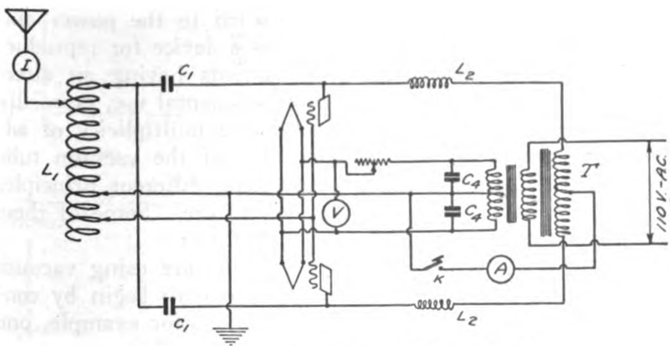


Fig. 47. Two-tube Self-rectifying Circuit

output circuit of a 250-watt power amplifier. This latter inductance is constructed with a special transmitting Litz.

The milliameter, A, reading to 250 M. A., and the radiation ammeter, I, reading to 5 amperes, complete the circuit.

As previously stated, Fig. 47 represents a two tube circuit in which the principal of self rectification is employed, one tube availing itself of one-half of the alternating current cycle, and the second tube the other half.

The nomenclature of this circuit conforms to that of Fig. 46, except that L_2 are radio frequency choke coils having an inductance of approximately two millihenries. Honeycomb coils may be used for this purpose.

CHAPTER VII

A 10-WATT POWER AMPLIFIER

THE reader's attention was called to the power amplifier in a previous chapter, as a device for reproducing in greater magnitude currents having an alternating or pulsating nature. For experimental use, especially in shore installations, this device has a multiplicity of advantages over other power generators of the vacuum tube type which operate in circuits involving different principles and which have been considered heretofore. Some of these advantages may be stated briefly as follows:

(1) Practically all experimenters who are using vacuum tube circuits for the first time are prone to begin by constructing low power equipment involving, for example, one or two 5-watt tubes, or one 50-watt tube. The progressive experimenter of today spares little expense in making his installation the best that can be had and very often even a small set represents an outlay of several hundred dollars. The time soon comes when a more powerful installation is required and, ordinarily, the construction of a 5 or 10-watt set does not, for example, permit of the mere substitution of two 50-watt tubes to form a 100-watt set, or the substitution of a 250-watt tube to form a ¼ kilowatt set. To scrap, or reconstruct the low-powered equipment then represents a distinct loss. Few experimenters are aware of the fact that by the addition of a power amplifier having the desired output all of the advantages of totally new equipment may be had and many more, which are inherent in the power amplifier.

(2) The frequency of the emitted wave is more or less independent of the constants of the antenna circuit, consequently, fading of the received signal is less liable to occur because of a swaying antenna or moving objects in the electro-static field of the antenna. Such fading is very pronounced in present day experimental C. W. transmitters not

employing the amplifier as a means of obtaining the desired power output.

(3) In ordinary radiophone circuits involving even moderate powers (50 watts) it is very difficult to obtain the telegraph to telephone transmitting range ratio that is pos-

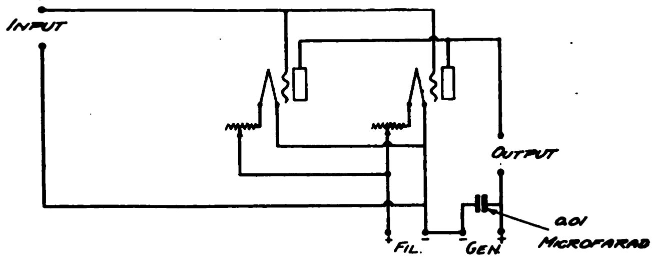


Fig. 48. Power Amplifier Circuit

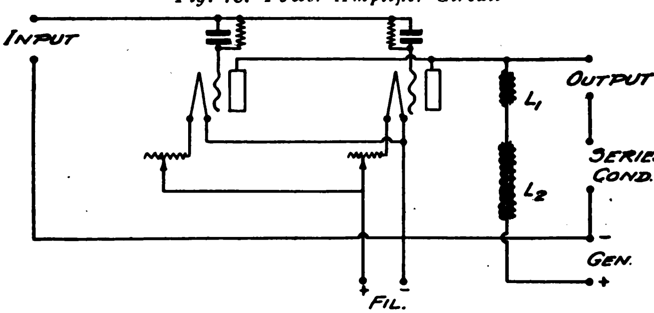


Fig. 49. Circuit for Use Either as an Amplifier or Oscillator

sible with much lower powers (5 watts) and oftentimes the experimenter is discouraged to learn that with his new 50-watt set he is obtaining no greater telephone range than was had with a previously constructed 5-watt set, although the radiation current is many times greater. This is due to the fact that the percentage modulation of the emitted wave is lower in the case of the higher-powered equipment. Distortion of the emitted wave also follows low percentage modulation. The use of the power amplifier overcomes all these difficulties, for the entire wave is amplified and the same percentage modulation obtains as was the case with the lower-powered equipment.

(4) Greater flexibility is possible in circuits involving the power amplifier.

Except for the details of construction, the power amplifier was quite thoroughly discussed in connection with Figs. 21 and 22 in Chapter 2.

Two power amplifier circuits are possible, one of which is illustrated in Fig. 48 and the other in Fig. 49.

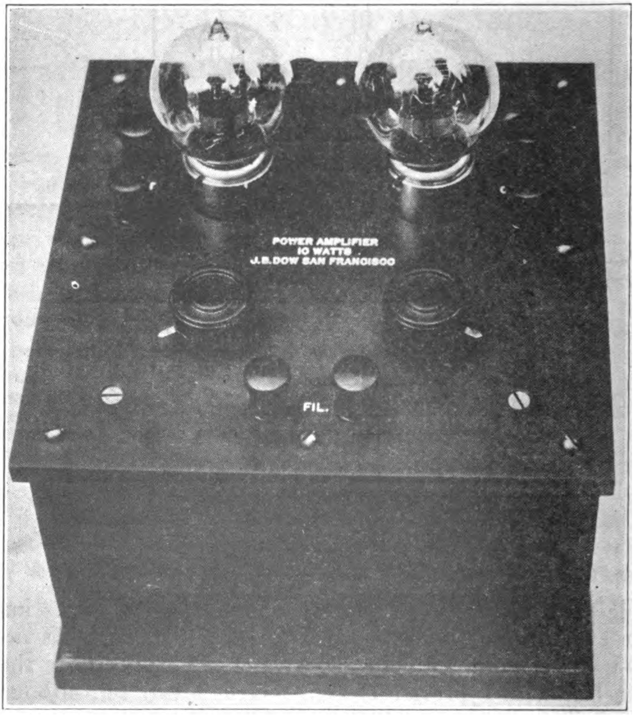


Fig. 50. 10-Watt Power Amplifier

It will be observed that the circuit of Fig. 48 is identical with the one used in Fig. 21 of Chapter 2, and is strictly a power amplifier circuit.

The circuit of Fig. 49 is a combination of a power amplifier and an oscillator circuit in that it may be used for either at will, and is therefore the more desirable because of its flexibility. For example the apparatus which is being

considered in this chapter is used as an oscillator in a 10-watt C. W. circuit in Fig. 42. Strictly speaking, a power amplifier does not require the use of a grid condenser and grid leak in the amplifier circuit because the necessary grid potential may be obtained by an adjustment of the input inductance L_1 of Fig. 21, which circuit also includes a C battery. However, in order to permit the use of the am-

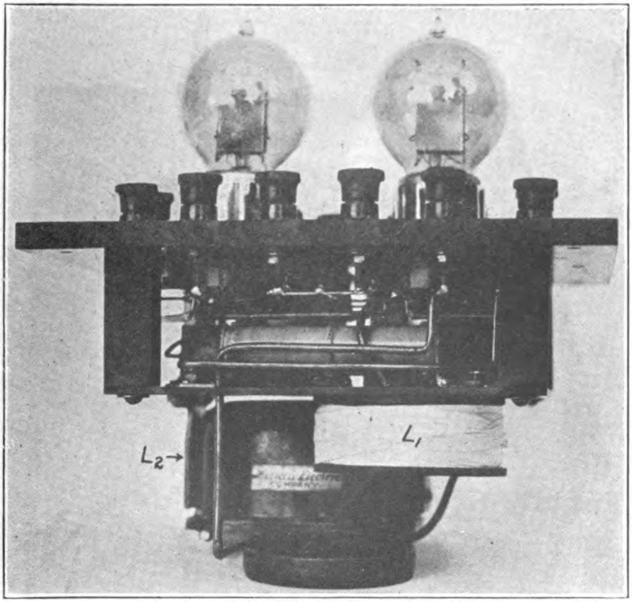


Fig. 51. Interior of 10-Watt Power Amplifier

plifier under consideration as an oscillator, a grid condenser and grid leak is provided for each tube.

Figs. 50 and 51 show two views of the completed apparatus which are self explanatory as to the matter of arrangement. The 250 turn honeycomb coil, L_1, and the shielded inductance, L_2, of Fig. 51 are, respectively, the radio frequency choke, L_1, and the audio frequency choke, L_2, of Fig. 49. The latter choke has an inductance of 2 henries, which is not an imperative value, for the one described in detail in Chapter 3 may be used with equal success.

Grid condensers, each having a value of 0.002 microfarad, are used with grid leaks of 5000 to 10,000 ohms in each grid circuit.

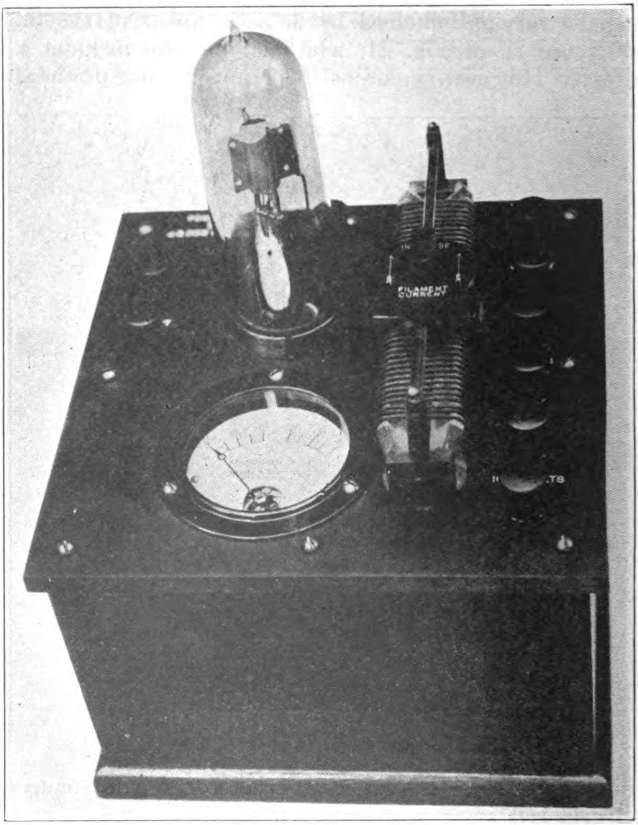


Fig. 52. 50-Watt Power Amplifier

To give the reader some idea as to the dimensions of this unit, it may be stated that the box of Fig. 50 has inside dimensions of 7 by 7 by 5¾ inches deep.

The terminals labeled "series condensers" in Fig. 49 should be shunted with a small variable condenser designed to withstand the maximum e.m.f. employed in the circuit,

and which should have a capacity of 0.001 microfarad. A small fixed condenser may be used in lieu of this, but it will be found that the variable feature is desirable in adjusting the circuit for maximum output.

Figs. 52 and 53 show two views of a 50-watt power amplifier constructed along similar lines, the only difference

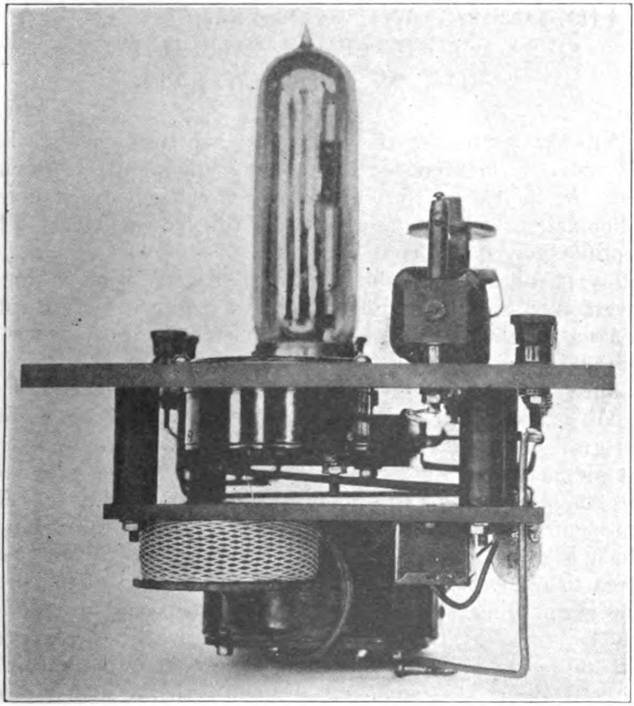


Fig. 53. Interior of 50-Watt Power Amplifier

being vested in additional insulation which is required in places in view of the use of a higher plate potential.

Either of the power amplifiers described above may be "driven" by a 5-watt oscillator as explained in conjunction with Fig. 21, and the experimenter will find that the results obtained far surpass those of other circuits not employing the amplifier, especially where voice modulation is desired.

CHAPTER VIII

THE DESIGN AND CONSTRUCTION OF A 250-WATT POWER AMPLIFIER AND C. W. TRANSMITTER

FROM a study of the preceding chapter the reader has become familiar with the power amplifier as a device for increasing the output of a previously constructed radiophone or other type of vacuum tube transmitter. The amplifier now under consideration is one employing a single 250-watt tube, and capable of being "driven" from a single 5-watt tube as a master oscillator and another 5-watt tube as a modulator if control of the emitted wave by voice is desired.

This amplifier is also designed to operate as a complete C. W. transmitter. It contains the necessary grid condenser and grid leak for this purpose as well as the input and output inductances. Figs. 54, 55 and 56 show three views of the completed apparatus (except for the wiring). All non-metallic parts of the completed unit, except the cabinet, which is of oak and 12½ by 11 by 16 in. inside and rabbitted to receive the front panel, are constructed of bakelite. The major dimensions of the various panels and sub-panels may be found by referring to Fig. 57. If the constructor will follow these dimensions carefully in cutting the required material, the expense incurred in manufacturing such a piece of apparatus will not be as great as might be expected and the finished product will be a device well worth the care necessary to construct same.

Since, from Figs. 54, 55 and 56, the details of the assembly are quite clear, it is considered unnecessary to include further detail in connection with Fig. 57. This figure also explains the method of supporting the vacuum tube, wherein standard Radio Corporation end mountings are suspended inside two bakelite rings by means of helical

springs. This method of suspension prevents possible damage to the tube from any shock received in handling the equipment, and is highly recommended.

Fig. 58 illustrates the circuit used in this combined power amplifier and C. W. transmitter. Reference to this figure

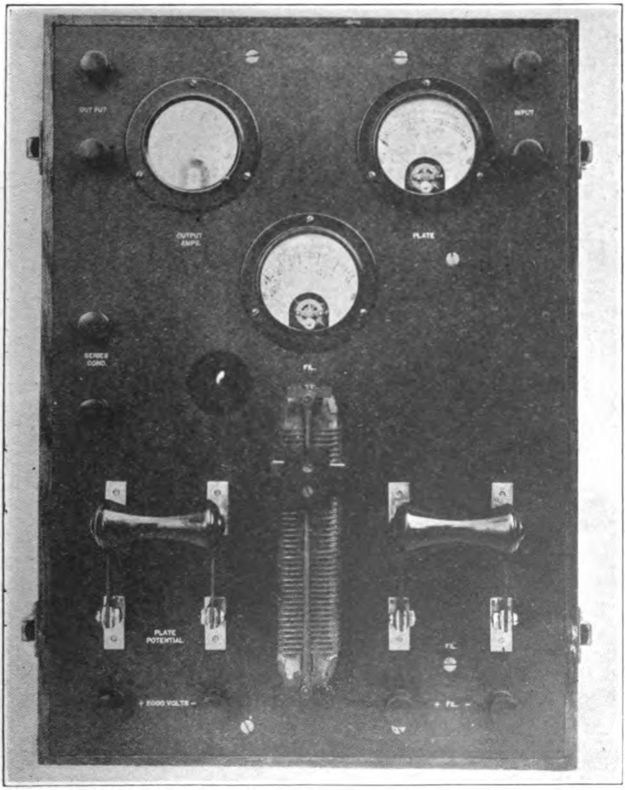


Fig. 54. Front View of 250-Watt Power Amplifier

will convince the reader of its flexibility and consequent utility. Because of this feature it is a most valuable asset to any radio laboratory.

By merely impressing a portion of the output of a small oscillator or radio phone set (see Fig. 21) upon the grid

circuit of the amplifier, and, of course, at the same time supplying the latter equipment with the necessary plate and filament energy, the entire output of the amplifier may be controlled with the same precision as the much lower-powered "driver."

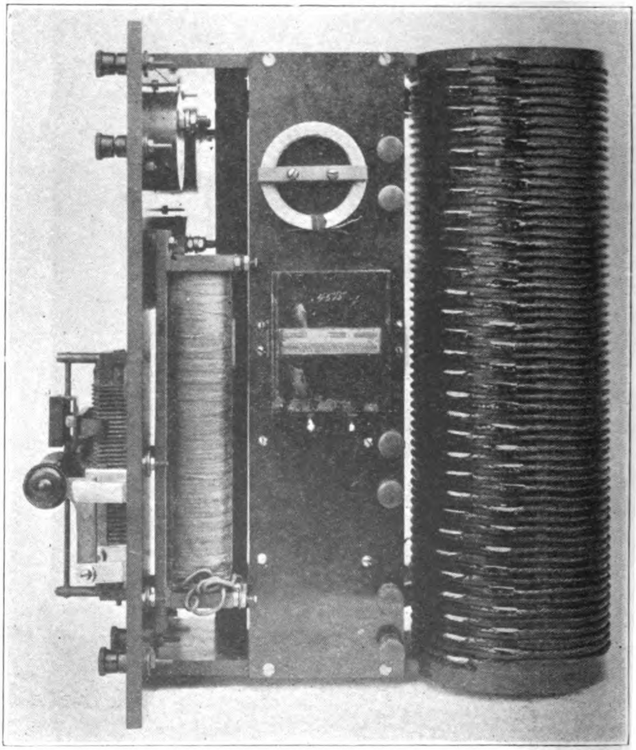


Fig. 55. Right Profile of 250-Watt Power Amplifier

If it is desired to use the device as an oscillator for the transmission of telegraph signals only, the master oscillator of Fig. 21 is unnecessary. To do this it is only necessary to connect as shown by the broken lines, these connections being simple post to post operations.

Either alternating or direct current may be used on the filament and plate. The process of shifting is a simple one and will be considered in detail later.

As stated in connection with Fig. 58, binding posts 1, 2, 3, 4 and 5 are located on the vertical sub-panel and are in

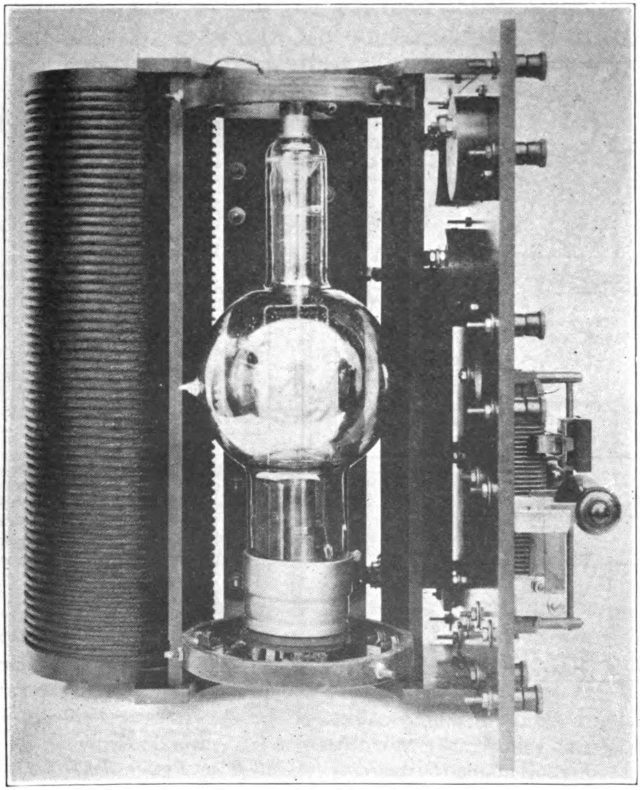


Fig. 56. Left Profile of 250-Watt Power Amplifier

evidence in Fig. 55. These posts provide a simple, efficient means for operating the device as an amplifier or oscillator. The balance of the binding posts provide exterior connections to the completed apparatus and are located upon the front panel. Some of these are not shown in the original

model from which the photograph in Fig. 54 was made, but in all subsequent models the additional posts were provided.

The grid condenser, C_1, and the grid leak, R_1, comprises a 0.002 microfarad mica dielectric condenser and a resistance of 5000 to 10,000 ohms. The necessary details for the construction of such a resistance will be found in Fig. 27.

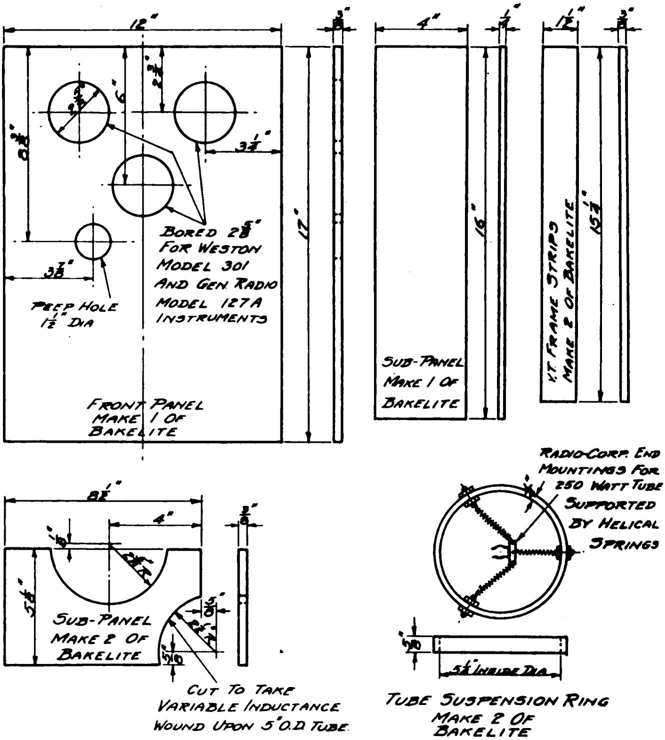


Fig. 57. Panel Dimensions for 250-Watt Power Amplifier

The condenser, C_2, of Fig. 58, is of the oil dielectric type shown as the left one in Fig. 59 and must be capable of withstanding 4000 volts. Its capacity should be approximately 0.002 microfarad. The smaller condenser of Fig. 59, while admirably suited to use in low power C. W. circuits, cannot supplant the one mentioned above, but is

merely shown in this figure for comparison. If an oil dielectric variable transmitting condenser is not available, a mica dielectric fixed capacity may be used in place of C_2 in Fig. 58.

The inductance, L_1, consists of a 250 turn honeycomb coil and prevents radio frequency energy from entering the supply circuit by way of the generator leads to the posts, 14 and 15.. In series with this radio frequency choke is the audio frequency choke, L_2, which prevents a damping of any audio frequency signal which is being transmitted. This latter choke also serves the important purpose of maintaining

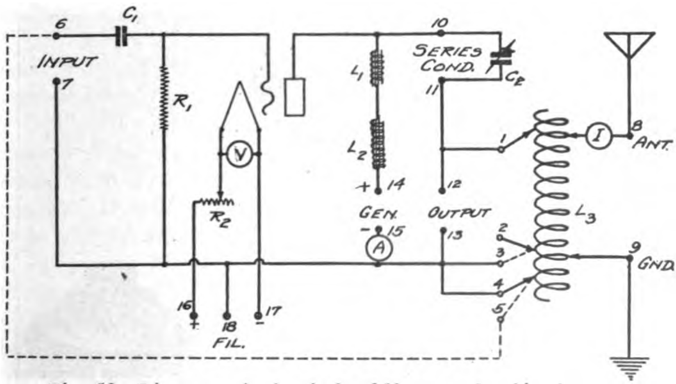


Fig. 58. Diagram of Circuit for 250-Watt Combined Power Amplifier and Oscillator

a steady current flow to the plate from the high voltage generator or other source of supply. If the device is to be used only for the amplification or generation of continuous waves at high frequencies the choke L_2 is unnecessary. The details of construction for L_2 will be found under Fig. 29 of a previous chapter. To smooth out the ripples caused by commutation and to provide a bypass for such radio frequency currents as get by the choke L_1, the posts, 14 and 15, should be bridged with a capacity of 0.5 microfarad. This capacity is not provided for in the instrument itself, because when alternating current of the voltage required is used to supply the tube via the plate, this capacity must be left out of circuit or a much smaller one must be provided. The reason for this is quite obvious.

The inductance, L_3, which is shown in Figs. 55 and 56, consists of sixty turns of 10 by 30 Litz twisted seven cord, around a 5 in. outside diameter bakelite tube. Different construction for this inductance is permissible, but in designing another type employing solid conductor in place of the above mentioned Litz, the reader is urged to consider the theory of eddy currents, which are very pronounced in power circuits operating within the scope of radio frequen-

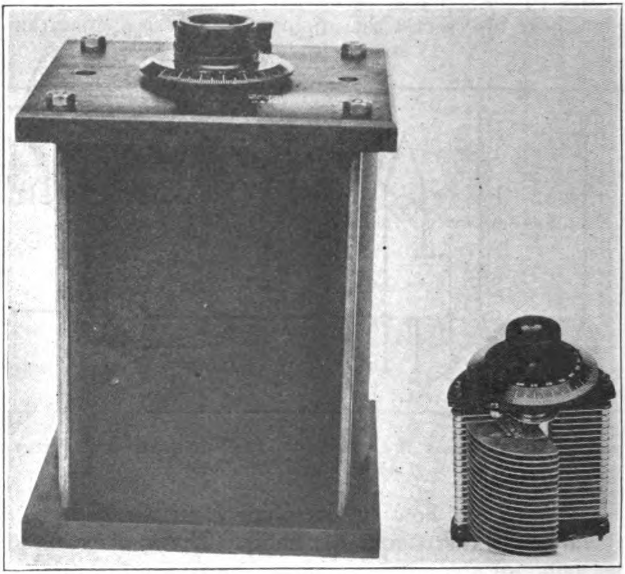


Fig. 59. Transmitting Condensers. Left, Oil Immersed; Right, Air Dielectric Type

cies. It would not be consistent with good engineering policies to use copper tubing less than 5/16 in. in diameter nor copper strip less than ¾ in. wide. The flexible leads to this inductance terminate at the binding posts provided on the vertical sub-panel. The process of soldering Litz is considered in detail in a subsequent chapter.

The filament voltmeter, V, which has a scale reading to 12, the milliammeter, A, with a scale reading to 250, and

the radiation ammeter, I, with a scale reading to 10, are standard equipment.

It will be seen in Fig. 58 that there are three posts marked "FIL." These provide for filament heating by either alternating or direct current and, of course, the former is to be preferred because of the resulting greater tube life. When alternating current is employed for this purpose, post number 18 is the mid tap to the filament transformer secondary. To eliminate the impedance of the transformer secondary to the high frequency pulsating currents flowing from the filament, a 0.5 microfarad paper dielectric condenser should be bridged across posts number 16 and 18, and 18 and 17. When direct current is used for filament supply, connect posts 17 and 18 together and apply the filament heating current to posts 16 and 17.

Neglecting the broken lines of Fig. 58, the device is connected for use as an amplifier of any high frequency pulsating or alternating current impressed upon the input terminals. It will be noted that the flexible leads to the variable output inductance are connected to posts numbered 1, 2, 4, 8, and 9. Post number 2 is a blank, and serves merely to support the flexible lead when its use is not desired.

To use the instrument as an oscillator or C. W. transmitter, shift the flexible lead from post number 2 to 3 and the one from post number 4 to 5 and connect posts 5 and 6 together. This will form a Hartley oscillating circuit which will be found to operate most efficiently.

CHAPTER IX

RECTIFIERS OF PLATE SUPPLY CURRENT FOR TRANSMITTING VACUUM TUBES

The Electrolytic Rectifier

DURING the early history of electro-chemistry it was found that when a plate of aluminum and a plate of lead or carbon were immersed in certain conducting solutions a current could be made to flow in one direction only. In other words, the combination acted as a valve which soon found a practical application as a rectifier of alternating current.

Essentially, such a rectifier consists of a lead and an aluminum plate immersed in a solution of ammonium phosphate or sodium borate. Both of these substances dissolve in water quite easily. The efficiency of such a device decreases as the current to be rectified increases, especially when such currents cause an appreciable temperature rise of the solution, and seldom exceeds 50 per cent. However, in radio work, where large currents are not required, the device generally operates at a maximum of efficiency and lends itself quite well to the task of supplying a high voltage direct or pulsating current.

The simplest form of electrolytic rectifier circuit is shown in Fig. 60 wherein one cell, consisting of two lead plates and one aluminum plate, are immersed in the solution of ammonium phosphate.

A single cell rectifier of this type is incapable of rectifying more than 50 to 70 volts effectively and where much greater voltages are to be rectified recourse must be had to additional cells in series as shown in Fig. 40-C wherein one cell is used for each 60 or 70 volts to be rectified. This limitation results from the difficulty in obtaining a sufficiently heavy film upon the aluminum plate which is the governing factor in the matter of output e.m.f.

The circuit of Fig. 40-C is one in which both sides of the alternating current cycle are rectified, with a result, insofar as construction is concerned, that twice as many rectifier units are required as would be the case if only one side of the cycle were rectified.

The advantage in rectifying both sides lies in a more nearly constant output e.m.f., which is desirable in radiophone work. Utilizing the entire cycle in this way makes it possible with a suitable smoothing out system to obtain a current that is only slightly pulsating.

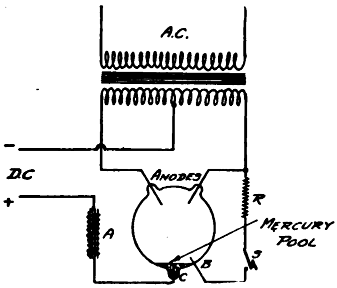


Fig. 61.
Mercury Arc Rectifier Circuit

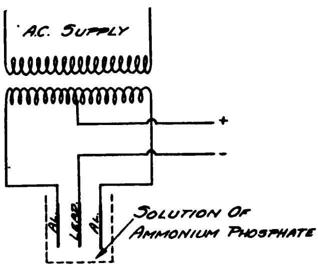


Fig. 60.
Simple Electrolytic Rectifier Circuit

The rectifier units mentioned above are quite inexpensive to construct since all the materials required are used to a great extent commercially. However, considerable time is required. As stated in Chapter V, pint Mason fruit jars may be used to good advantage in constructing the units, although small jars 1 in. by 1 in. by 6 in. deep inside will lend themselves to compactness more conveniently. The larger jars, of course, contain more solution, and heating, which lowers the efficiency of the rectifier very appreciably, is not so apt to occur.

Fill each jar to about three-quarters of its height with a saturated solution of ammonium phosphate or sodium borate (borax) and immerse in each a plate of aluminum and one of lead. For the small currents required for vacuum tube work (equipment employing not more than two of the 50-watt tubes) these plates should not be wider than 1 in. nor immersed in the solution to a depth greater than 3 in. and

should be separated from each other at least ½ in. and not more than 2 in.

To "form" the aluminum plates, which consists in depositing the white crystaline rectifying film upon them, each unit should be connected to a rather high voltage source which will ordinarily be most convenient in the form of

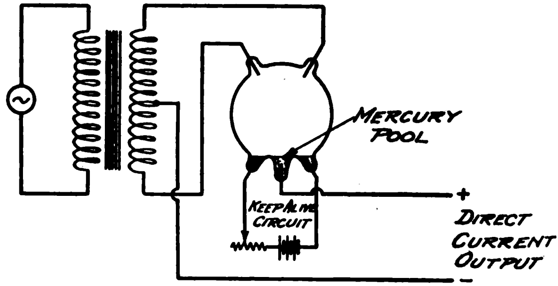


Fig. 62. Mercury Arc Rectifier With "Keep Alive" Circuit

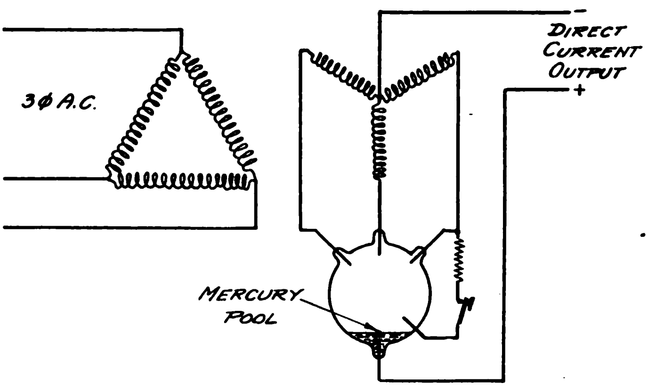


Fig. 63. Mercury Arc Rectifier Circuit for Three Phase Supply

alternating current from the transformer which will ultimately supply the current to be rectified. A secondary winding supplying 500 volts on open circuit will work very well, since during the initial "forming period" the voltage drop in the winding will govern the current flow and as the film is formed the voltage will rise gradually. When the plate is sufficiently well formed, sparking will be noticeable over its

surface. During this process, the electrolyte should be kept cool by circulating water around the unit. This step is very important; likewise, it is imperative that pure aluminum plates be used.

Mercury Arc Rectifier

Of late, mercury arc rectifiers have presented themselves in the field of radio as a means of obtaining the much sought high voltage direct currents, and every application points to success. One argument favoring such a device is based upon the fact that the mercury arc is an article of commerce. These have been used for a number of years in connection with series arc light projects in many localities and, coincidently, they have been developed to function efficiently in just the power outputs and voltages that are required for high power vacuum tube work. As an example, a 4 ampere 3500 volt mercury arc rectifier is more or less standard and one of these could quite easily supply ten 250-watt tubes. Smaller rectifiers of this type could readily be developed for lower powered tube installations if the demand warranted it, and no doubt we shall see them on the market soon.

The simplest form of mercury arc rectifier circuit is shown in Fig. 61. Near the top of the figure is the alternating current transformer which steps up the voltage to the desired value. The extreme ends of the secondary winding terminate at the anodes of the valve, while the mid tap forms the negative lead of the direct current output circuit. The positive pole or negative electrode of the valve is at C, Fig. 61, and the rectified current flows from this terminal thru the sustaining coil, A, to the direct current power consuming device which, in the case under consideration, is the vacuum tube transmitter.

The resistance, R, and the auxiliary electrode, B, comprise the starter for the arc. To start, the tube is tipped to one side, causing the mercury to close the circuit CB thru the disconnect S. The spark or arc thus formed volatilizes some of the mercury, which lowers the resistance of the conducting path between the anodes and the cathode and this breaks down, forming the necessary arc. During half of the cycle the current flows from one anode to the cathode and during the remaining half it flows from the other.

Were it not for the inductance, A, which must be of the order of several henries, the arc would have to be restarted by means of the auxiliary circuit after each half cycle. Upon the collapse of the magnetic field around this inductance, following an extinction of the arc when the alternating wave reaches zero in value, an e.m.f. is impressed across the anode and cathode sufficiently great to re-ignite the arc, and the other half cycle is rectified in the same manner.

Unless the tube is being operated at its designed output

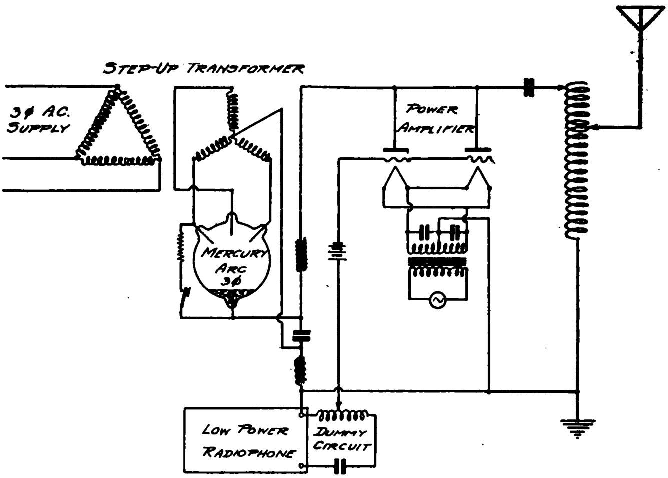


Fig. 64. Circuit Diagram of High Powered Tube Transmitter Employing Three Phase Alternating Current Pre-rectified by Means of a Mercury Arc Rectifier.

the inductance, A, will not function properly. To overcome this, some rectifiers are provided with a "keep alive" circuit wherein the mercury is continuously being volatilized. Such a circuit is shown in Fig. 62. In radio work where the load is not constant this latter type of rectifier is used. Inductances and capacities are used also in the rectifier output leads to smooth out any irregularities in the direct current.

For radio work which requires a very constant direct current source, three phase mercury arc rectifiers are often used. Such a circuit which requires no "keep alive" auxiliary is shown in Fig. 63. In this case the mercury arc is

not extinguished because the potential across the tube never reaches zero value.

A high power tube circuit of the power amplifier type wherein the mercury arc rectifier is employed, is shown in Fig. 64.

THE KENETRON RECTIFIER

The kenetron or vacuum tube rectifier has, of recent years, been receiving considerable application in C. W. work with tubes. The theory of such apparatus is so simple that little explanation is necessary. This theory is, of course, based upon the unilateral conductivity of a vacuum tube comprising a heated filament and a cold plate. Fig. 65 illustrates the simplest form of such a circuit wherein an alternating current source, A, supplies power to the trans-

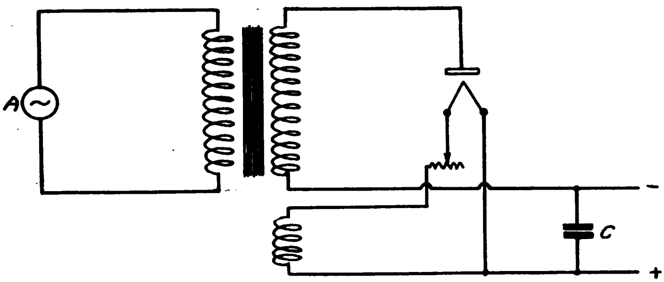


Fig. 65. Simple Thermionic Rectifier Circuit

former, T, which steps up the initial e.m.f. to that required in the form of direct current for the plate supply of the oscillator tubes and modulator tubes of the transmitter. The transformer, T, has two secondaries, one of which supplies a filament heating current for the rectifier tube.

By virtue of the above mentioned unilateral conductivity of the rectifier tube a current flows across the ionized path between plate and filament only when the plate is at a positive potential, the result being that a pulsating direct current is supplied to the condenser, C, where it is stored as energy and delivered to the transmitter as required. Such an arrangement provides for the rectification of only one-half of each cycle and the other half while not lost, is not used.

Fig. 40-B shows a previously explained circuit wherein both sides of the alternating current cycle are utilized.

CHAPTER X

THE DESIGN OF A LOW POWERED CIRCUIT FOR DUPLEX OPERATION

THE present trend of radiophone construction is toward apparatus which is capable of duplex operation wherein a two way simultaneous conversation may be maintained as in wire telephony. The self contained duplex feature of such apparatus also permits of direct connection to land lines without the necessity for complete isolation of the receiver from the transmitter or the use of separate directive antennae for transmitter and receiver.

Two types of duplex apparatus are in use to a very limited extent at the present time. One of these types employs a sensitive relay which, thru the medium of microphone currents, automatically places the antenna of the talker's station on the transmitter. When the speaker breaks his conversation, the relay automatically places his receiver on the antenna again. This might more appropriately be termed a "break in" system. As might be expected, a number of mechanical and electrical difficulties limit the successful operation of such equipment at the present stage of development.

The second type of duplex equipment balances out, insofar as the talker's receiver is concerned, any interference which might otherwise be caused by his own transmitter. At the same time, the receiver is operative, in that any received signal from an outside source will be heard.

Several types of this apparatus have been developed to a greater or lesser extent and it might be well to mention that, in principal, they are all more or less identical. Of these, the Carson system has been the most successful up to the present time.

Schematically, the Carson system consists of a balanced network (see Fig. 66) containing the source of high fre-

quency oscillations, A; the artificial antenna, B; the real antenna or radiating member, D; and the divided inductance, L_1, L_2, which is, in effect, the primary of the receiver coupler to which is symetrically coupled the secondary, L_3.

In Fig. 66, assuming the current flow at a particular instant as indicated by the arrows, it divides thru the two equal and symetrical inductances, L_1 and L_2, part flowing

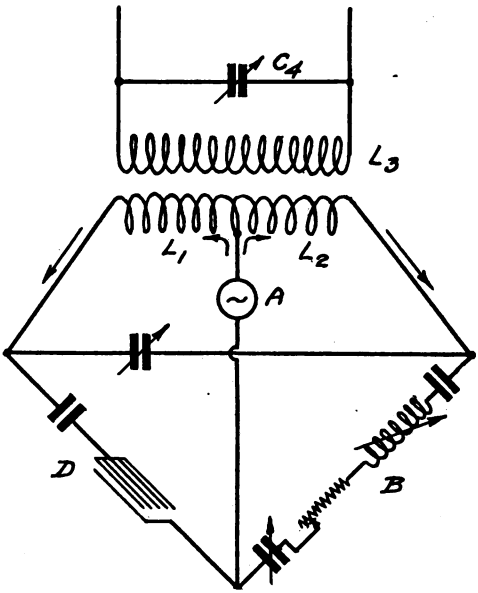


Fig. 66. Equivalent Bridge Circuit of Transmitter, Receiver and Balancer

to the radiating system, D, and part to the dummy circuit or balancer circuit, B. Now if the currents thru the two inductances, L_1 and L_2, are equal, no induced potential will occur across the receiver secondary, L_3, and consequently no signal will be detected by the receiver, which has originated from the source A.

If, however, a potential is induced in the branch, D, from an outside source, as for example a distant station, an unequal current will flow thru L_1 and L_2 with a result

that induction will take place in L_3 and the signal will be detected.

The problem which presents itself then is that of dividing the currents in the branches L_1 and L_2 equally.

It is a well known fact that for a given frequency of

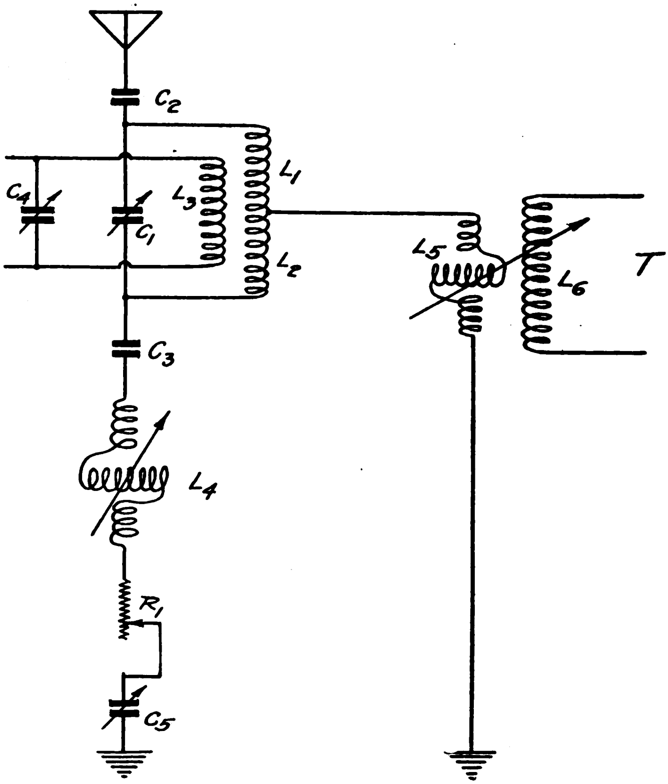


Fig. 67. Circuit Diagram of Carson Duplex Radiophone

oscillation equal currents will flow in each branch if the impedances are equal. For one definite frequency, equal impedances could be obtained with a large capacity and small inductance value in one branch and a small capacity and large inductance value in the other, but with the slightest change in frequency the impedances would change, re-

sulting in unequal current distribution. By considering the equation for impedance it will be seen that in order to hold the same impedance in two circuits regardless of the frequency, the capacity, inductance, and resistance must have identical respective values in both circuits.

The problem then resolves itself into one of determining the proper values for capacities, inductances and resistances in the circuits.

The circuit of Fig. 67 represents a network which, in view of the capacities between component parts and the dissimilarity in the effects of lumped and distributed capacity, becomes very complex and ordinary methods of solution wherein definite circuit constants may be obtained, are not applicable. As an example, the receiver, secondary coil L_3, is coupled to the primary, L_1 and L_2, which is also a part of the transmitting circuit. Any change in the capacity relations between these three inductances, then, would influence the adjustment of the other. To minimize this effect, these three inductances, or rather the two, for L_1 and L_2 are identical, must be shielded insofar as the altering of capacity relations is concerned. This is done by enclosing L_3 in a thin copper shell, slotted so as to prevent the shell's forming a short circuited loop. Another deviation which prevents the use of ordinary principles of design is the fact that a dummy antenna or balancing circuit consisting of lumped constants is used to balance a real antenna with distributed constants.

In the circuit of Fig. 67, T is the transmitter inductively related to L_5, which is an inductance of the variometer type having a minimum inductance of 20 microhenries and a maximum of 80. These values, as well as those of future ones, are based upon the requirements of a 200 to 400 meter set. One side of this inductance is connected to earth and the other to the center tap of the shielded inductance L_1 L_2, where the circuit divides. The values of L_1 and L_2 should be 60 microhenries each.

The lower branch of the above mentioned divided circuit comprises the balancer. This contains the small series condenser, C_3, having a capacity of approximately 300 micromicrofarads; the variometer, L_4, having an inductance continuously variable from 5 to 30 microhenries, and shielded

within a copper shell to eliminate variable capacity relations with adjacent apparatus; the resistance, R, which is continuously variable from 0 to 10 ohms, and the variable condenser, C_5, which has a maximum capacity of about 2000 micro-microfarads. This latter variable condenser must also be shielded for reasons previously stated.

The upper branch of the circuit contains the real antenna and the series capacity, C_2, which has the same capacity as that of C_3.

The variable capacity, C_4, across the receiver primary, L_3, facilitates tuning in for receiving, but has practically no effect upon the wavelength of the transmitter.

Assuming that such a circuit as the one illustrated in Fig. 67 is adjusted to the desired wavelength, which is dependent upon the adjustment of the variometer, L_5, and that it is desired to balance the circuits in such a manner that the transmitted signal will not be heard in the sender's receiver, the first step is to adjust L_4, R_1, and C_5, in such a manner as to approximate the constants of the real antenna. Usually, the correct values will be unknown and it will be necessary to adjust and readjust until silence is obtained in the receiver for several transmitting wavelengths. It must be understood here, that it is quite easy to obtain the necessary balance for one transmitting wavelength, but this will only suffice for that particular wavelength, and any very small adjustment in the transmitter itself would be liable to make the set noisy.

For the successful operation of a duplex circuit of the type described above it is necessary to go to extremes in shielding the apparatus, particularly the balancer and transmitter. Both cabinets, as well as the front panels where possible, should be covered inside with thin copper sheet or wire netting and all battery and generator leads should be run in lead armor. The armor of adjacent conductors should be connected together at intervals with soldered connections and grounded to maintain it at zero potential.

CHAPTER XI

NOTES FOR THE EXPERIMENTER AND CONSTRUCTOR

FOR the purpose of arrangement this chapter will be divided into three parts, the first of which will be composed of notes concerning the operation of vacuum tube transmitters, and the remaining two parts will be devoted to mechanical processes and the selection of apparatus respectively.

Notes Upon the Subject of Operation

1. The use of alternating current for filament heating often increases the life of the tubes from two to three times.

2. Protective fuses should be used in filament circuits to insure the tubes against excessive currents which are liable to destroy same. It must be borne in mind, however, that ordinary fuses do not function rapidly enough to protect the filaments against sudden increases in the current. Very fine iron wire operates as a protective device for filaments more satisfactorily than the lead-tin compositions, but when exposed to air the life of such a fuse is very short .

3. An impromptu *voltmeter* for high voltages such as are employed in the plate circuits of vacuum tubes may be made by connecting a number of 110 volt two candlepower lamps in series and estimating the voltage by the number of lamps in series and the brilliancy.

4. In smoothing out systems, little is gained by inserting a choke coil in the negative lead from the generator because this side of the circuit is usually grounded and is therefore at zero potential.

5. The circuit of Fig. 68 should be used in preference to that of Fig. 69 for the reason that if the filament battery became grounded or leaky to earth, the input inductance

would not become short circuited and prevent the set from oscillating. Theoretically, however, the circuit of Fig. 69 is the better because the grid is more easily maintained at a negative potential.

6. An antenna having a natural period not greater than 70 per cent of the transmitting wavelength should be used for best results.

7. A counterpoise should always be used where practicable to reduce undesirable resistance. Frequently the radiation may be doubled in this manner.

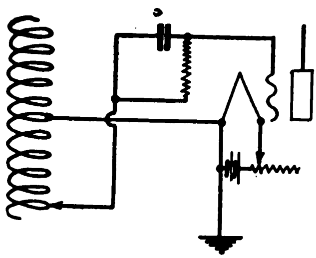


Fig. 68

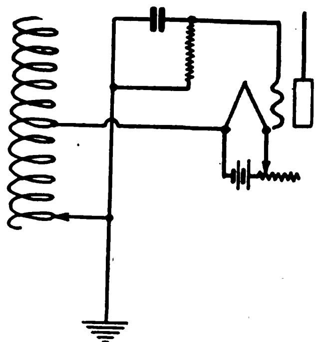


Fig. 69

8. Very often a given transmitter cannot be made to oscillate on the lower wavelengths and the cause may generally be traced to an excessive natural period of the antenna or to excessive antenna resistance which results in high impedance at the high frequencies concurrent with short wavelengths. Shortening the antenna in the first case or installing a counterpoise in the second will usually clear the difficulty.

9. A landline may be linked with a radiophone directly thru the modulation transformer for transmitting and thru a quarter inch spark coil for receiving, using the primary in the landline.

10. In adjusting a vacuum tube transmitter, use a small milliameter in the grid circuit to measure the current flow. If the grid current is excessive, the current drawn from the

generator will be excessive. A large grid current results in poor modulation.

11. The actual output when using two tubes as oscillators in a transmitter will be approximately twice as great as when only one is used, but the radiation will by no means be doubled. The reason is that the current squared times the resistance determines the output.

12. Porcelain insulation in antenna systems being used with C. W. is greatly superior to other types commonly used. In this connection, glazed porcelain only must be employed.

13. When using two or more small generators in series to obtain high voltages, insulate each machine from the other in order to prevent the breaking down of insulation between the windings and the frames.

14. Do not attempt to decrease the output of a tube transmitter by dimming the filaments without first decreasing the plate voltage, or a chain of phenomena will result which is liable to decrease the life of, or totally destroy the filaments.

15. In operating vacuum tube transmitters, always heat the filaments to the proper brilliancy first, then cut in the plate supply voltage. When shutting down a tube transmitter cut out the plate supply voltage first.

16. When employing the Heising system of modulation, wherein control is obtained by variations in the grid potential of the modulator tubes, a C battery must be used. If the plates of the modulator tubes become red, the grid potential may not be sufficiently negative and more C battery should be used.

Notes Concerning Mechanical Processes

1. Following is a list of tools and equipment that every experimenter should possess: Small electric soldering iron and accessories; three inch bench vise; small breast drill and set of drills, size 0 to 60; tap wrench and taps of common sizes; jeweler's saw frame and supply of saws; combination square; pliers, including flat nose side cutters, long nose side cutters, diagonal cutters, gas pipe, and round; an assortment of screw drivers; small calipers; eight inch scale; drill gauge; thread gauge; assortment of files; small hammer; center punch; countersink tool; scriber; dividers; hack saw,

and an assortment of machine screws. Wood working tools are also necessary if the experimenter does his own cabinet making.

2. Large holes are easily cut in bakelite or similar substances by using a boring bar in a drill press and boring half way thru from each side. In this connection a small centering hole must first be drilled for lining up the tool.

3. A jeweler's saw is one of the handiest tools that the experimenter could possess, yet one is rarely ever found in the average constructor's workshop. To those who are unfamiliar with such a tool, it is simply a very fine hack saw which finds an almost unlimited number of applications.

4. A metal cutting band saw is much preferred to a circular saw for cutting bakelite and similar substances.

5. Black crystalizing enamel is used to produce the beautiful checked finish oftentimes found on metal parts of radio apparatus. This is easily applied with a camel hair brush and checks in the process of drying.

5. The modern tendency in the construction of vacuum tube transmitters is to use Litz for conductors of high frequency currents of any appreciable magnitude and this excellent tendency is somewhat thwarted by the difficulties usually experienced in soldering same. Litz composed of individual wires smaller than No. 32 does not ordinarily warrant usage in view of the difficulties encountered in soldering. Where the wires are larger than this, the enamel may be removed quite easily by heating to redness in a clean flame such as is given by hydrogen gas or alcohol, and plunging the heated section in alcohol, repeating the process once or twice. This procedure breaks down the enamel in such a manner as to make it easily removable by immersing in hot solder and scraping lightly. The enamel comes off quite easily and floats to the surface of the solder. The application of a very small quantity of good anti-corrosive soldering paste will then cause the solder to run in, making a solid mass when cool. The greatest difficulty that will be experienced will be in obtaining a clean frame such as is given by hydrogen gas.

Notes Upon the Selection of Apparatus

1. Litz inductances are far superior to edgewise wound copper strip inductances or to inductances wound with copper tubing as regards high frequency resistance. The latter type, however, has a slight, though unappreciable, advantage

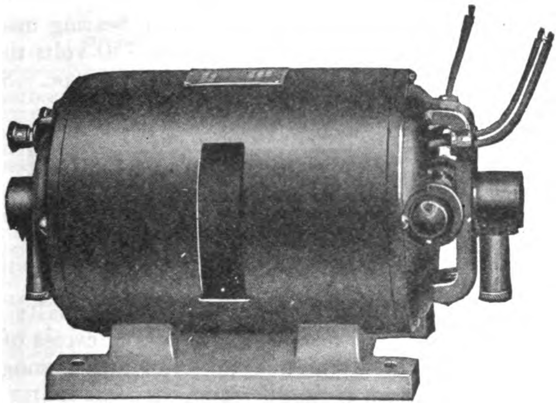


Fig. 70. Two Bearing Single Unit Motor Generator

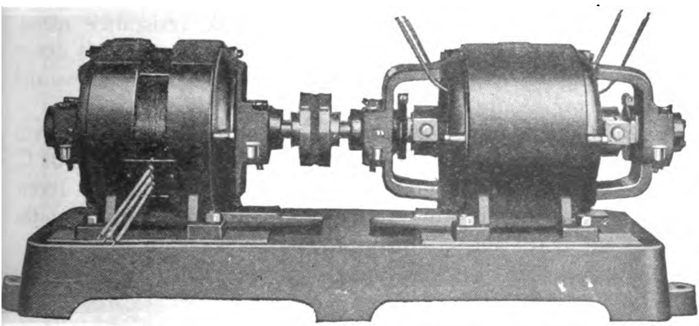


Fig. 71. Double Commutator Generator

over the second type. Inductances wound with solid round conductor are inferior to other types and this inferiority increases as the size increases beyond a certain limit for a given current flow. It likewise increases as the size decreases below a certain limit for a given current flow.

2. Generally speaking, a modulation transformer having a primary to secondary turn ratio of 1 to 30 will be found most satisfactory.

3. Small motor generators having outputs under 200 watts are most desirable in the form of two bearing single unit machines. A unit of this type is shown in Fig. 70. Larger sets for generating voltages under 1500 are most satisfactory in the form of two unit four bearing machines. Where the output voltage is in excess of 750 volts the generator should be of the double commutator type. Such a

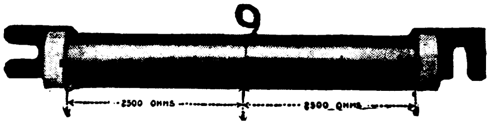


Fig. 72. A Rugged Grid Leak Resistance

machine as manufactured by the Electric Specialty Co. is shown in Fig. 71. For producing voltages in excess of 1500, two such generators connected in series and having their frames insulated from each other and from the motor which may be most conveniently mounted between them, are recommended.

4. Fig. 72 shows a type of grid leak resistance manufactured by the Radio Corporation of America. This device is meeting with great favor because of its ruggedness and facility for mounting.

5. Though not mentioned heretofore, a motor driven chopper is an ideal device for modulating the output of C. W. transmitters for non-oscillating tube or detector reception. A device of this kind may be inserted either in the grid, or oscillating circuit.

ALUMINUM AND COPPER, SOLID WIRE—DIMENSIONS AND WEIGHTS

Am. G'ge B. & S. No	Diam. Mils.	Area: Circular Mils. (d^2) 1 mil.= .001 inch	Area: Square Mils. d^2 x .7854	Lbs. per 1,000 Ft. Alu-minum	Lbs. per 1000 Feet Copper	Feet per Lb. Alu-minum	Feet per Lb. Copper
0000	460.000	211600.00	166190.	195.	641.	5.120	1.560
000	409.640	167805.00	131790.	154.	509.	6.490	1.965
00	364.800	133079.40	104520.	122.	403.	8.200	2.480
0	324.860	105534.00	82886.	97.1	320.	10.30	3.125
1	289.300	83694.20	65733.	77.0	253.	12.98	3.950
2	257.630	66373.00	52130.	61.1	202.	16.35	4.950
3	229.420	52634.00	41339	48.4	159.	20.66	6.290
4	204.310	41742.00	32784	38.4	126.	26.04	7.930
5	181.940	33102.00	25998.	30.4	100.	32.90	10.00
6	162.020	26250.50	20617.	24.2	79.	41.30	12.65
7	144.280	20816.00	16349.	19.2	63.	52.10	15.88
8	128.490	16509.00	12966.	15.2	50.	65.70	20.00
9	114.430	13094.00	10284.	12.1	39.	82.60	25.06
10	101.890	10381.00	8153.2	9.55	32.	104.8	31.25
11	90.742	8234.00	6467.0	7.57	25.	132.2	40.00
12	80.808	6529.90	5128.6	6.00	20.	166.7	50.00
13	71.961	5178.40	4067.1	4.76	15.7	210.0	63.70
14	64.084	4106.80	3146.9	3.78	12.4	264.5	80.64
15	57.068	3256.70	2557.8	2.99	9.8	334.4	102.1
16	50.820	2582.90	2028.6	2.38	7.9	420.2	126.6
17	45.257	2048.20	1608.6	1.88	6.2	531.9	161.3
18	40.303	1624.30	1275.7	1.495	4.9	668.8	208.3
19	35.890	1288.10	1011.66	1.185	3.9	843.0	256.4
20	31.961	1021.50	802.28	.940	3.1	1063.	322.6
21	28.462	810.10	636.25	.745	2.5	1343.	400.0
22	25.347	642.70	504.78	.590	1.9	1695.	526.3
23	22.571	509.45	400.12	.469	1.5	2132.	666.5
24	20.100	404.01	317.31	.372	1.2	2688.	813.0
25	17.900	320.40	251.64	.294	.97	3402.	1031.
26	15.940	254.01	199.50	.234	.77	4273.	1298.
27	14.195	201.50	158.26	.185	.61	5405.	1640.
28	12.641	159.79	125.50	.147	.48	6802.	2083.
29	11.257	126.72	99.526	.117	.39	8540.	2564.
30	10.025	100.50	78.933	.0924	.31	10808.	3226.
31	8.928	79.71	62.604	.0733	.24	13643.	4167.
32	7.950	63.20	49.637	.0582	.19	17182.	5263.
33	7.080	50.13	39.372	.0461	.15	21692.	6670.
34	6.304	39.74	31.212	.0365	.12	27397.	8333.
35	5.614	31.52	24.756	.0290	.095	34483.	10526.

Table 1

ALUMINUM SOLID WIRE, HARD DRAWN—RESISTANCE (61%)

Am. Gauge B. & S No.	Ohms per 1000 Feet	Ohms per Mile	Feet per Ohm	Ohms per Pound
0000	.0804	.4245	12400.	.000414
000	.101	.5333	9860.	.000656
00	.128	.6758	7820.	.001043
0	.161	.8501	6200.	.001659
1	.203	1.072	4920.	.002636
2	.256	1.352	3900.	.004195
3	.323	1.705	3090.	.006676
4	.408	2.154	2450.	.010617
5	.514	2.714	1950.	.016821
6	.648	3.421	1540.	.026859
7	.817	4.314	1220.	.042755
8	1.03	5.438	970.	.067806
9	1.30	6.864	770.	.107595
10	1.64	8.660	610.	.171465
11	2.07	10.93	484.	.272450
12	2.61	13.78	384.	.433023
13	3.29	17.37	304.	.689730
14	4.14	21.86	241.	1.09708
15	5.22	27.56	191.	1.74555
16	6.59	34.80	152.	2.76589
17	8.31	43.88	120.	4.41782
18	10.5	55.44	95.5	6.99992
19	13.2	69.70	75.7	11.1355
20	16.7	88.18	60.0	17.7155
21	21.0	110.9	47.6	28.1586
22	26.5	139.9	37.8	44.7100
23	33.4	176.4	29.9	71.2819
24	42.1	222.3	23.7	113.400
25	53.1	280.4	18.8	180.255
26	67.0	353.8	14.9	286.806
27	84.4	445.6	11.8	456.211
28	106.0	559.7	9.39	723.676
29	134.0	707.5	7.45	1150.10
30	169.0	892.3	5.91	1828.09
31	213.0	1125.	4.68	2910.66
32	269.0	1420.	3.72	4618.20
33	339.0	1790.	2.95	7342.85
34	428.0	2260.	2.34	11672.4
35	540.0	2851.	1.85	18615.6

Table 2

TABLE OF
WIRE AND SHEET METAL GAUGES

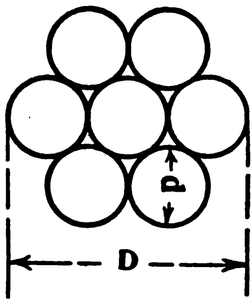
No.	Brown & Sharpe	London	American Screw Co.'s Screw Wire Gauge	New British Standard	Birmingham
4-0	.46000	4540		.400	454
3-0	40964	4250	.0315	.372	.425
2-0	36480	3800	0447	.348	.380
0	32486	.3400	0578	.324	.340
1	28930	3000	.0710	.300	.300
2	25763	.2840	0842	.276	.284
3	.22942	2590	.0973	.252	.259
4	20431	2380	.1105	.232	.238
5	18194	2200	.1236	.212	.220
6	16202	.2030	.1368	.192	.203
7	14429	1800	1500	.176	.180
8	12849	1650	1631	.160	.165
9	11442	1480	1763	144	.148
10	10190	1340	.1894	.128	.134
11	09074	1200	.2026	.116	.120
12	08081	1090	.2158	.104	.109
13	07196	0950	.2289	.092	.095
14	06408	0830	.2421	080	083
15	05707	0720	.2552	072	.072
16	05082	0650	2684	064	.065
17	04526	0580	2816	056	058
18	04030	0490	.2947	048	.049
19	03589	0400	.3079	040	042
20	03196	0350	3210	036	.035
21	02846	0315	.3342	032	032
22	02535	0295	3474	028	.028
23	02257	0270	.3605	024	.025
24	02010	0250	.3737	022	.022
25	01790	0230	3868	020	.020
26	01594	0205	4000	.018	.018
27	01420	01875	4132	.0164	.016
28	01264	01650	4263	0148	.014
29	01126	01550	4395	.0136	.013
30	.01003	01375	4526	.0124	.012
31	008928	01225	4658	0116	.010
32	007950	01125	4790	.0108	.009
33	007080	01025	.4921	.0100	.008
34	.006305	00950	5053	.0092	.007
35	.005615	00900	.5184	.0084	.005
36	005	00750	5316	0076	.004
37	004453	00650	5448	.0068	
38	003965	00575	5579	.0060	
39	003531	005	5711	0052	
40	003145	.0045	.5842	.0048	

Table 3

Conductor Table

Table for Determining the Diameter of a Litz or Antenna Cable for Various Number of Conductors

Number Conductors	3	7	12	19	27	37	48	61	75	91	108	127
Factor....	2⅙	3	4⅙	5	6⅙	7	8⅙	9	10⅙	11	12⅙	13j



The diameter of a cable of any number of strands is approximately given by

$$D = 1.155d\ \sqrt{N}$$

Where D=diam. of cable, d=diam. of strand, N= number of strands.

Example—A cable formed of 61 conductors will have a diameter of 9 times the diameter of the conductor.

Calculating this by the formula gives 9.02 instead of 9. For a small number of conductors, especially where the cable does not form according to system shown in the illustration, the error is greater.

Table 4

Conductor Table

Table Showing the Number of Conductors Required of any B. & S. Gauge, to Have the Same Cross-Sectional Area as Another, Larger Gauged, Wire.

Difference of B. & S. Gauges	No. of smaller sized wires required to give same area as the larger wire	Difference of B. & S. Gauges	No. of smaller sized wires required to give same area as the larger wire
0	1.	17	51.5
1	1.3	18	65.
2	1.6	19	81.9
3	2.	20	103.3
4	2.5	21	130.3
5	3.2	22	164.3
6	4.	23	207.1
7	5.1	24	261.2
8	6.4	25	329.4
9	8.1	26	415.3
10	10.2	27	523.7
11	12.8	28	660.4
12	16.2	29	832.7
13	20.4	30	1050.
14	25.7	31	1324.
15	32.3	32	1670.
16	40.9	33	2105.

Example—How many No. 30 B. & S. Gauge wires will be required to form a cable having the same area as No. 18 wire?

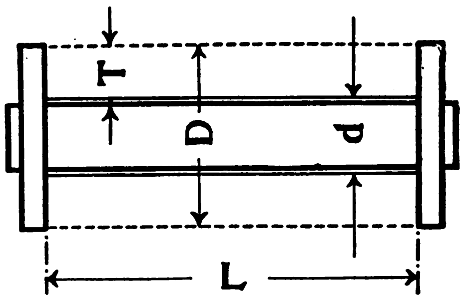
Look in column of Difference of Gauges for 12 (the difference between 30 and 18), opposite 12 will be found 16.2, the required result.

Note—While a No. 18 wire has 16.2 times the area of a No. 30, it does not follow that a close cable formed of the No. 30 wire will have 16.2 times the carrying capacity of a No. 30 wire, because the area exposed to radiate heat in the close cable is much less than that of 16 wires of No. 30 totally exposed. For the same reason, such a cable will have a greater carrying capacity than a solid No. 18 wire, everything else being equal.

Table 5

COIL WINDING CALCULATIONS

The following formulae are being given without the usual individual illustrations. We offer no apology for this departure from custom, as we believe the various factors and relations will be sufficiently clear to those requiring their use In publishing the following tables of data, we would call attention to the fact that it is impossible to accurately state the values of turns per square inch, ohms per cubic inch, etc. These values are dependent upon winding conditions, and will, therefore, vary considerably between different winding departments, between different types of machines, and even between different sizes of coils The tables as given are average values and results derived therefrom do not under ordinary conditions vary more than 5% either way. All resistance data is based on 68° F. or 20° C We would further state that the following formulae and tables are those in constant use by ourselves.



Referring to the diagram, let

L = Length of winding space.
D = Outside diameter of winding.
d = Diameter of insulated core.
M = Mean diameter.
T = Thickness of winding
V = Winding volume.
R = Total resistance.
r = Resistance per cubic inch (Table B).
s = Resistance per lineal inch (Table A).
p = Resistance per pound (Table C).
N = Total number of turns.
n = Turns per square inch (Table D)
W = Total weight of insulated wire.
w = Weight per cubic inch (Table E)
m = Weight per 1000 feet (Table F)

Formulae showing the relations between above factors·

$$T=\frac{D-d}{2}$$

$$R=Vr=\pi MLTr=\pi MNs=Wp$$

$$M=\frac{D+d}{2}=T+d$$

$$N=LTn=\frac{R}{\pi Ms}$$

$$D=\sqrt{\frac{4V+\pi Ld^2}{\pi L}}$$

$$W=\frac{R}{p}=Vw=\pi MLTw=\frac{\pi MNm}{12000}$$

$$V=\pi MLT=\frac{\pi L(D^2-d^2)}{4}=\frac{R}{r}-\frac{W}{w}$$

To find size of wire, take the size having in the following tables a value nearest corresponding to that determined by either of the following formulae:

$$r=\frac{R}{V} \qquad n=\frac{N}{LT}$$

COIL DATA

We give below examples showing the easiest methods of working out the three principal forms of coil winding problems:

Given Bobbin and Wire—to find the winding data.

Example: L=4" D=3" d=1⅛" No. 24 Beldenamel.

D=3.000
d=1.125 subtracting
2|2.875 dividing
T=1.438 $\left(\frac{D-d}{2}\right)$
d=1.125 adding
M=2.563 (T+d)
πM=3.1416×2.563
=8.038
V=8.038×4×1.438
=46.23 cu. in. (πMLT)

R=46.23×4.488 (Vr)
=207.4 ohms
N=4×1.438×2100 (LTn)
=12,090
Also N=207.4÷(8.038×.002136) $\left(\frac{R}{\pi Ms}\right)$
=12,060 turns
W=46.23×.2178 (Vw)
=10.07 lb.
Also W=207.4÷20.60 $\left(\frac{R}{P}\right)$
=10.07 lb.

Given Bobbin, Resistance, and Insulation of Wire—to find size of wire.

Example: L=2¾" D=1½" d=½" 400 ohms Silkenamel.

By the above method: r=400÷8 635 $\left(\frac{R}{V}\right)$
V=8.635 cu. in. =46.29 ohms

Table 7 indicates No. 30 Silkenamel as being nearest in value to that required.

Given Winding Length and Diameter of Insulated Core, Resistance, and Wire—to find the number of turns.

Example: L=2 d=.4" R=125 ohms No. 30 S. S.

V=125÷58.45 $\left(\frac{R}{r}\right)$
=2.140 cu. in.

$$D=\sqrt{\frac{(4\times 2.140)+(3.1416\times 2\times .4^2)}{3.1416\times 2}}$$

=1.235"

Then by the first method:
T=.4175
N=2×.4175×6810 (LTn)
=5,693 turns

RESISTANCE PER INCH

B. & S.	OHMS	B. & S.	OHMS	B. & S.	OHMS
8	0000552	19	.0006698	30	.008583
9	.0000659	20	.0008450	31	.01082
10	.0000831	21	.001065	32	.01365
11	0001047	22	.001343	33	.01722
12	.0001322	23	.001693	34	.02171
13	.0001666	24	.002136	35	02736
14	.0002101	25	.002692	36	.03452
15	.0002649	26	.003396	37	.04352
16	0003341	27	004281	38	.05487
17	0004212	28	005399	39	06920
18	.0005312	29	.006809	40	.08725

Table 6

OHMS PER CUBIC INCH

B & S.	Beld-enamel	Single Cotton	Double Cotton	Single Silk	Double Silk	Cot-enamel	Silk-enamel
8	.00315	00293	00265		...	00287	...
9	00475	00435	00388		..	00422	.....
10	.00748	00698	00631		.	00664	...
11	.01183	01088	.00974		.	.01047	...
12	01878	01718	.01519		.	01651	....
13	0295	0266	0233		...	0251	...
14	.0464	0416	.0359		.....	.0393	....
15	0734	0650	0551		..	0609	.....
16	1162	1042	.0869	1172	1092	0966	.1089
17	1840	1613	1331	1840	1705	1508	.1718
18	2910	2508	2008	2910	2672	2326	.2682
19	4560	3890	3048	4565	4145	3560	.4165
20	7200	6008	4605	7165	6430	5440	.6500
21	1 134	9240	6920	1 123	9960	8310	1.007
22	1 800	1 515	1 162	1 766	1 545	1.354	1 578
23	2.820	2 320	1 744	2 743	2.370	2.066	2.438
24	4.488	3 557	2 596	4 293	3 642	3.150	3.790
25	7 080	5 440	3 822	6 645	5.570	4.820	5.867
26	11 27	8 300	5 740	10 05	8.510	7.318	9.100
27	17 75	12 52	8.330	15 75	12.89	11.08	13.92
28	28 34	18.90	12 15	24 83	19 54	16.74	21.75
29	44 32	28 05	17.30	37 65	29.08	24.91	33.12
30	70 15	42.08	25 15	58 45	43.75	37.08	50.56
31	110 4	62.45	36.05	89 40	65.08	55.40	77.60
32	172.6	91.45	50 76	134.7	95 40	81.35	116.8
33	279 0	134.0	71.30	208.0	140 5	120.8	179.1
34	433.2	195.6	99.77	309 5	205.8	175	265.
35	684.5	281 8	138 7	459.6	297.3	251 7	396.7
36	1094	405 7	191.6	685.6	429	364 2	597.3
37	1723	576.7	263.	1014	613.5	522	887.5
38	2693	817 7	357	1497	875.8	735.5	1294
39	4332.	1148	480.	2193	1235	1048	1927.
40	6770	1605	650	3202.	1736	1461.	2791.

Table 7

OHMS PER POUND

B. & S.	Beld-enamel	Single Cotton	Double Cotton	Single Silk	Double Silk	Cot-enamel	Silk-enamel
8	0124	.0124	0123			0122	
9	0197	0197	0197			0194	
10	0314	.0313	0310			0310	
11	0497	0498	0492			0488	
12	0791	0788	0778			0775	
13	1255	1250	1232			1227	
14	2005	1960	.1953			1958	
15	3180	3150	3080			3100	
16	5050	4990	4885	5080	5040	4890	5000
17	8051	7900	.7730	8075	8005	7785	7960
18	1 278	1 253	1 218	1 283	1 270	1 250	1 292
19	2.032	1 990	1.915	2 038	2 015	1 950	2 002
20	3.239	3 145	3.050	3 235	3 190	3 100	3 183
21	5 138	4.980	4.760	5 140	5 070	4 870	5 030
22	8.186	7.865	7.435	8 150	8 035	7 720	8 000
23	12.97	12.41	11 78	12 94	12 75	12 16	12.63
24	20.60	19.65	18.35	20 58	20 15	19.20	20 00
25	32.70	31 10	28.60	32 58	31 75	30.15	31 72
26	51 95	48.90	44.50	51 50	50 25	47 60	50 30
27	82.55	77 15	68.00	81 75	79 60	74 90	79 60
28	131.2	121 5	106 5	129 6	125 9	118 2	126 1
29	208.7	192.0	167	205.8	198.0	187 0	198 8
30	331 5	303 0	260.5	326.0	310 0	289 5	312 2
31	526.5	471.0	400 0	517 0	486.0	451.5	493 0
32	836 5	735.0	607 5	816.0	758.5	699.8	776.0
33	1332	1135.	910 0	1280.	1180.	1085.	1227
34	2118.	1762.	1351.	2020.	1850	1680.	1931
35	3352	2730.	2050	3175	2905.	2550.	3020
36	5340	4170.	3040.	5035	4500.	3907	4755
37	8480.	6360	4340.	7885	7050.	5750.	7420.
38	13490	9400	6290	12350	10780	8465.	11520
39	21450.	13800.	8875	19550	16500.	12370.	18000
40	34100	20150	12500	31500	24380	18350	27810

Table 8

TURNS PER SQUARE INCH

B. & S.	Beld-enamel	Single Cotton	Double Cotton	Single Silk	Double Silk	Cot-enamel	Silk-enamel
8	57	53	48	......	......	52	......
9	72	66	59	......	......	64	......
10	90	84	76	......	......	80	......
11	113	104	93	......	......	100	......
12	141	129	114	......	......	124	......
13	177	160	140	......	......	151	......
14	221	198	171	......	......	187	......
15	277	245	208	......	......	230	......
16	348	312	260	351	327	289	326
17	437	383	316	437	405	358	408
18	548	472	378	548	503	438	505
19	681	581	455	682	619	532	622
20	852	712	545	848	761	644	769
21	1065	868	650	1055	935	780	946
22	1340	1128	865	1315	1150	1008	1175
23	1665	1370	1030	1620	1400	1220	1440
24	2100	1665	1215	2010	1705	1475	1775
25	2630	2020	1420	2470	2070	1790	2180
26	3320	2445	1690	3005	2510	2155	2680
27	4145	2925	1945	3680	3010	2590	3275
28	5250	3500	2250	4600	3620	3100	4030
29	6510	4120	2560	5530	4270	3660	4865
30	8175	4900	2930	6810	5100	4320	5890
31	10200	5770	3330	8260	6010	5120	7170
32	12650	6700	3720	9870	6990	5960	8560
33	16200	7780	4140	11850	8160	7020	10400
34	19950	9010	4595	14250	9480	8060	12200
35	25000	10300	5070	16800	10870	9200	14500
36	31700	11750	5550	19850	12430	10550	17300
37	39600	13250	6045	23300	14100	12000	20400
38	49100	14900	6510	27300	15960	13400	23600
39	62600	16600	6935	31700	17850	15150	27850
40	77600	18400	7450	36700	19900	16750	32000

Table 9

POUNDS PER CUBIC INCH

& S.	Beld-enamel	Single Cotton	Double Cotton	Single Silk	Double Silk	Cot-enamel	Silk-enamel
8	.2540	.2362	.2154	....	....	.2352	....
9	.2411	.2208	.1969	....	....	.2175	....
10	.2382	.2230	.2036	....	....	.2142	....
11	.2381	2185	.1980	....	....	.2145	....
12	.2374	.2180	.1953	....	....	.2131	....
13	.2350	.2128	.1891	....	....	.2045	....
14	.2314	.2122	.1838	....	....	2007	....
15	.2308	.2063	.1789	....	....	.1964	....
16	.2301	.2089	.1777	.2318	.2150	.1975	.2178
17	.2287	.2042	.1722	.2279	.2130	.1937	2158
18	.2277	.2001	.1648	.2268	.2103	.1860	.2075
19	.2262	.1955	.1592	.2240	.2058	.1826	.2062
20	.2224	.1912	.1510	.2215	.2015	.1754	.2041
21	.2208	.1856	.1454	.2186	.1965	.1706	.2002
22	.2198	.1926	.1563	.2167	.1923	.1754	.1973
23	.2173	.1869	.1481	.2121	.1858	.1712	1930
24	2178	.1810	.1414	.2116	.1814	.1641	.1896
25	.2165	.1748	.1337	.2040	.1754	.1598	.1849
26	.2170	.1697	.1290	.1952	.1693	.1537	.1810
27	.2151	.1624	.1225	.1927	.1619	.1479	.1749
28	.2160	.1556	.1141	.1915	.1552	.1416	.1725
29	.2128	.1461	.1036	.1830	.1468	.1332	.1666
30	.2121	.1388	.0966	.1793	.1411	.1281	.1619
31	.2097	.1326	.0901	.1729	.1341	.1227	.1574
32	.2064	.1244	.0836	.1651	.1257	.1162	.1505
33	.2094	.1181	.0784	.1625	.1191	.1113	.1458
34	.2045	.1111	.0738	.1532	.1112	.1042	.1372
35	.2041	.1032	.0677	.1447	.1023	.0987	.1313
36	.2049	.0973	.0630	.1361	.0954	.0933	.1256
37	.2032	.0907	.0606	.1286	.0870	.0908	.1196
38	.1996	.0870	.0568	.1212	.0812	.0869	.1123
39	.2019	.0832	.0541	.1122	.0749	.0847	.1070
40	.1985	.0797	.0520	1017	.0712	0796	.1003

Table 10

WEIGHT PER 1000 FEET IN POUNDS

B. & S.	Beld-enamel	Single Cotton	Double Cotton	Single Silk	Double Silk	Cot-enamel	Silk-enamel
8	50.55	50 60	51.15	....	....	51.25	....
9	40.15	40.15	40.60	....	....	40.70	....
10	31.80	31.85	32.18	....	....	32.26	....
11	25.25	25.30	25.60	....	....	25.66	....
12	20.05	20.10	20.40	....	....	20.48	....
13	15.90	15.99	16.20	....	....	16.32	....
14	12.60	12.73	12.91	....	....	12.90	....
15	10.00	10.10	10.33	....	....	10.27	....
16	7.930	8.025	8.210	7.890	7.955	8.180	8.010
17	6.275	6.395	6.540	6.260	6.315	6.480	6 340
18	4.980	5.080	5.235	4.970	5.015	5.160	5.040
19	3.955	4.035	4.220	3.940	3.990	4.120	4.010
20	3.135	3.218	3.373	3.132	3.173	3.275	3.190
21	2.490	2.561	2.685	2.488	2.520	2.625	2 545
22	1.970	2.048	2 168	1.976	2.006	2.118	2 045
23	1.565	1.635	1.727	1.570	1.593	1.668	1.608
24	1.245	1.304	1.398	1.247	1.272	1 335	1.283
25	.988	1.039	1.129	.994	1.018	1 071	1 018
26	.7845	.8335	9140	7905	.8100	.8570	.8100
27	.6220	.6660	7560	.6280	.6450	6845	6445
28	.4940	.5325	6075	.4980	.5140	.5480	.5140
29	.3915	.4255	4890	3970	.4130	.4375	.4120
30	.3105	.3400	.3955	3160	.3330	.3555	.3295
31	2465	.2762	.3257	2517	2678	.2874	.2635
32	.1960	.2230	2700	.2100	2170	.2348	.2115
33	.1550	1816	.2270	1611	1750	1904	1683
34	.1230	1478	1928	1290	.1412	1551	1348
35	.0980	.1202	.1600	.1035	1130	1286	1085
36	.0776	0994	.1361	0823	0920	1062	0872
37	.0616	.0822	1204	.0663	.0740	0908	0704
38	.0488	0702	1049	.0534	0623	0778	0572
39	0387	0602	0937	.0424	0504	0669	0463
40	.0307	0519	.0838	.0345	.0429	0571	0376

Table 11

OUTSIDE DIAMETERS

in inches

B. & S.	Beld-enamel	Single Cotton	Double Cotton	Single Silk	Double Silk	Cot-enamel	Silk-enamel
8	.1306	.1355	.1415	....	....	.1376	....
9	.1165	.1214	.1274	....	....	.1235	....
10	.1040	1079	.1129	....	....	.1100	....
11	.0927	.0967	.1017	....	....	.0987	....
12	.0828	.0868	.0918	....	....	.0888	....
13	.0740	.0780	.0830	....	....	.0800	....
14	.0661	.0701	.0751	....	....	.0721	....
15	.0591	.0631	.0681	....	....	.0651	....
16	.0528	.0558	.0608	.0528	.0546	.0578	.0548
17	.0470	.0503	.0553	.0473	.0491	.0520	.0490
18	.0421	.0453	.0503	.0423	0441	.0471	.0441
19	.0377	.0409	.0459	.0379	.0397	.0427	.0397
20	.0337	.0370	.0420	.0340	.0358	.0387	.0357
21	0302	.0335	.0385	.0305	.0323	.0352	.0322
22	.0269	0293	.0333	.0273	.0291	.0309	0289
23	.0241	.0266	.0306	.0246	.0264	.0281	.0261
24	.0215	.0241	.0281	0221	.0239	.0255	.0235
25	.0192	.0219	.0259	0199	0217	.0232	.0212
26	.0171	0199	.0239	.0179	.0197	0211	.0191
27	.0153	0182	.0222	0162	.0180	0193	.0173
28	.0136	.0166	.0206	.0146	.0164	.0176	.0156
29	.0122	.0153	0193	0133	.0151	.0162	.0142
30	.0109	0140	0180	0120	0138	0149	.0129
31	.0097	.0129	.0169	.0109	.0127	0137	.0117
32	.0087	01195	01595	00995	.01175	.0127	.0107
33	.0077	01108	.01508	.00908	.01088	0117	.0097
34	.0069	.01030	01430	00830	.01010	.0109	.0089
35	.0062	00961	.01361	00761	.00941	.0102	.0082
36	.0055	00900	.01300	00700	.00880	.0095	.0075
37	.0049	00845	.01245	00645	.00825	.0089	.0069
38	.0044	.00796	.01196	00596	.00776	.0084	.0064
39	.0039	.00753	.01153	.00553	.00733	.0079	.0059
40	.0035	.00714	.01114	.00514	.00694	.0075	.0055

Table 12

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